SEWAGE WORKS JOURNAL

VOL. XII JULY, 1940 No. 4

Special Feature

PRELIMINARY PLANS FOR CHICAGO CONVENTION

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SEWAGE WORKS JOURNAL

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A Bimonthly Journal devoted to the advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of sewage works.

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The DORRCO MONORAKE,

Dorrco Monorake at Conway, Arkansas. Consulting Eng.: M. Z. Bair, Little Rock, Ark.

AN IMPROVED MECHANISM FOR RECTANGULAR SETTLING TANKS

ADVANTAGES

ALL LENGTHS—Widths Up to 3 Times Normal
Up to 40 ft. widths, I-beam design.
Up to 75 ft. widths, truss design.

AUTOMATIC OVERLOAD RELIEF
Rake blades swing upwards automatically if overload is encountered.

NO SUBMERGED BEARINGS
All bearings and metal to metal wearing parts are above the water level.

SINGLE HOPPERS
One depression for sludge collection.

SKIMMING IN EITHER DIRECTION
Skimmer can be supplied to skim either toward or away from influent.

SINGLE DRIVE FOR MULTIPLE UNITS
Drive two or more Monorakes from a single motor-drive unit.

Close-up of Raking Mechanism

The Dorrco Monorake, the result of a Development Program begun several years ago, is now represented by 25 successful commercial installations made over a period of 5 years. It is essentially a balanced raking mechanism for the continuous removal of sludge from *existing* rectangular sedimentation tanks.

Two balanced raking mechanisms, alternating in the raking and idling positions, are supported and operated from a traveling car. Two types of Monorakes are provided—the open type, illustrated above, and the submerged type where ice conditions are anticipated.

Dorrco Monorakes possess many new advantages cited at the left. Consequently these units are not subject to many of the limitations inherent in the conventional types of rectangular cleaning mechanism.

Write for descriptive literature on the Dorrco Monorake—an improved rectangular sedimentation unit.

DORRCO

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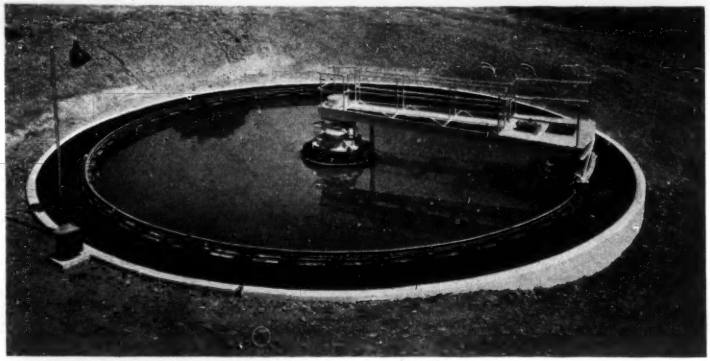
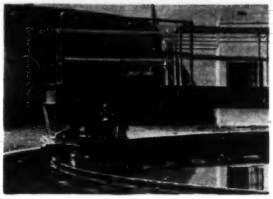
SONOMA and NEW ULM SELECT





TOP: Final Dorr Clarifier at Sonoma with circular Automatic Magnetite Filter around periphery.

ABOVE: Close up of cleaner element of Automatic Magnetite Filter.

AUTOMATIC MAGNETITE FILTERS To POLISH HIGH RATE FILTER EFFLUENTS

The model 0.75 M.G.D. sewage treatment plant of Sonoma State Home, Eldridge, Cal., consists of a single stage Biofiltration System followed by an Automatic Magnetite Filter. At New Ulm, Minn., this same type of filter is used in conjunction with a Halvorsen System of High Rate Trickling Filters.

The Automatic Magnetite Filter consists of a 3 inch layer of sized magnetite ore, supported on a screen and periodically cleaned by a moving solenoid which alternately lifts and releases a narrow strip of ore. A counterflow of wash water, introduced as the layer is lifted, carries off imbedded fines and renews the life of the bed.

Automatic Magnetite Filters, wherever installed, polish plant effluents to a uniform degree—remove the finest solids at a lower cost per ton than any other device operating over the same range. That, in a nutshell, is why Automatic Magnetite Filters make every type of sewage treatment plant do a bigger and better job.

APPLICATIONS

- **In Plain Sedimentation**
  Less settling capacity required and a 40 per cent improvement in effluent.
- **In Chemical Precipitation**
  50 per cent less chemical consumption; less time for coagulation and settling.
- **In Activated Sludge**
  Less settling and aeration tank capacity; less compressed air.
- **In Trickling Filters**
  If ahead, less primary settling tank capacity.
  If behind, less humus tank capacity.
- **In Biofiltration Systems**
  Less final settling capacity required and a better final effluent.
- **In Industrial Waste Treatment**
  Better final effluents at lower installation and operating costs.

Write for your copy of the Automatic Magnetite Filter Bulletin

THE AUTOMATIC MAGNETITE FILTER IS MARKETED EXCLUSIVELY BY THE DORR COMPANY, INC.

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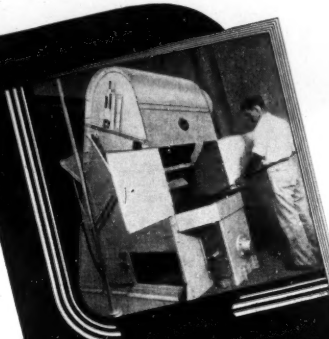

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YOUR PROBLEM IS SCREENING SEWAGE OR SHREDDING SCREENINGS...

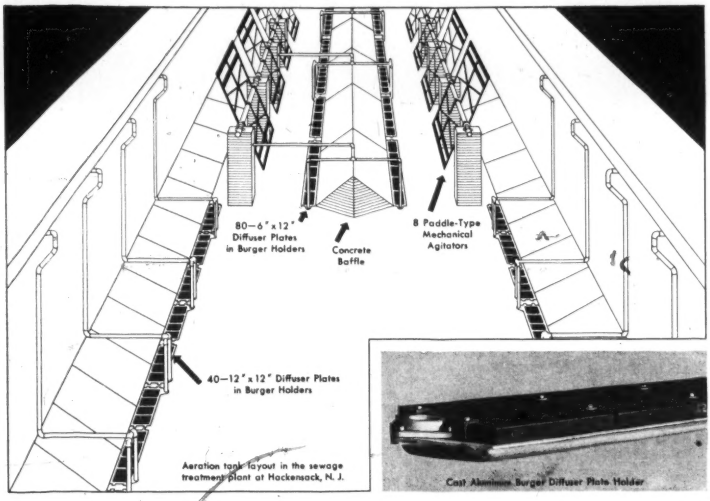
Sanitary engineers! Sewage plant operators! Anyone who is responsible for the efficient screening and disposal of municipal or industrial sewage should have a copy of this new book which describes Rex Mechanically Cleaned Bar Screens and Rex Triturators! Complete with detailed design data and application information, it is a valuable reference book to keep in your files.

Bulletin 319 also contains reprints of two articles written by experienced sanitary engineers. They describe in detail the benefits of using Rex Triturators and Rex Mechanically Cleaned Bar Screens in their plants.

Whether you're modernizing an old plant or building a new one, you need this fund of information close at hand. Send for your copy now! Address Sanitation Equipment Division, Chain Belt Company, 1606 W. Bruce St., Milwaukee, Wisconsin.

REX CHAIN BELT COMPANY OF MILWAUKEE

SANITATION EQUIPMENT


80—6" x 12" Diffuser Plates in Burger Holders
Concrete Baffle
8 Paddle-Type Mechanical Agitators
40—12" x 12" Diffuser Plates in Burger Holders
Aeration tank layout in the sewage treatment plant at Hackensack, N. J.
Cast Aluminum Burger Diffuser Plate Holder

These aeration tanks are planned for flexible operation

This interesting installation of air diffusers and mechanical agitators is in service at the Hackensack, New Jersey, sewage treatment plant. Employment of these two mediums in different combinations, to suit variable operating conditions, makes the system extremely flexible.

A row of wide diffuser plates is placed along the side of each aeration tank, for the first third of its length. Then, an A-shaped concrete baffle divides the tank down the middle, and two rows of narrower diffuser plates flank this baffle. The action of these plates is supplemented by large paddle wheels.

Cast Aluminum holders of the Burger design simplify installation and maintenance of diffuser plates. Holders carrying five plates each are handled as units, their light weight making the job go faster and easier. Plates are removed without danger of breakage, simply by loosening several bolts; they are made air- and water-tight by durable rubber gaskets. These holders are non-rusting.

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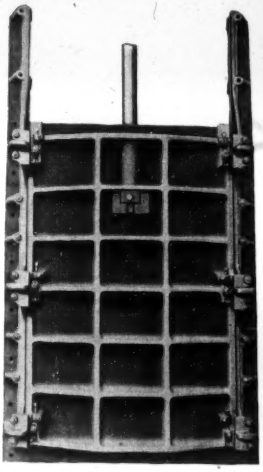
Chapman Sluice Gates are outstanding in all fields of application. Every gate is backed by a heritage of seventy-five years of successful experience in sluice gate design and manufacture. From this rich experience, Chapman has developed standardized lines embracing a range of types and sizes to meet all usual conditions, at substantial savings in cost and time of delivery. Interchangeable parts also facilitate installation and reduce cost of repairs or replacements in the field. Check your specifications with Chapman's *Sluice Gate Handbook.* Copy on request.



7′ x 7′ Table 6 Sluice Gate Adjustable Side Wedges, Rising Stem Type

Chapman

Automatic Cone Valves

Cut-Away View Automatic Cone Valve

Chapman Automatic Cone Valves are ideally suited for a number of important uses in sewage treatment, due to their smooth waterway and positive operation.

Recommended for: Sewage pump discharge check valves; Control of sludge chamber levels; Quick operating for grit chambers; Air blower checks on activated sludge.

Motor Units & Floorstands

For the electrical operation of gate valves and sluice gates, the Chapman Motor Unit and Motor Operated Floorstand will be found highly efficient and dependable. They are rugged and extremely simple, and may be operated at the unit or by remote control. Seating to any predetermined tightness is controlled by the Chapman *Limit Switch,* eliminating all possibility of jamming.

Motor Operated Floorstand

THE CHAPMAN VALVE

INDIAN ORCHARD,

FOR SEWAGE WORKS

Typical Iron Body Gate Valve, Bronze Mounted, Solid Wedge, Rising Stem, Flanged Ends

Chapman

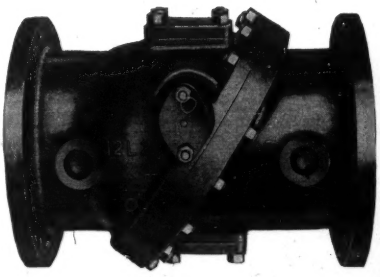
IRON BODY GATE VALVES

Chapman is well equipped to meet all needs of the sewage field for valve equipment of every type. Wide use of Chapman valves in this field is good evidence of the quality and service which may be expected of all Chapman products. Chapman Iron Body Gate Valves have a long and enviable record in sewage applications. The standardized lines include all types and sizes to meet every conceivable need. Selection from Chapman's standardized lines means the best valve which can be produced for the service intended, with maximum service at minimum cost.

Chapman

TILTING DISC CHECKS

These check valves, unique in design and operation, are especially adapted to various applications in the sewage works field. Many of the objectionable characteristics of conventional type swing checks have been overcome in the Tilting Disc Check, due to the bell-crank action of the disc and the streamlined waterway. Slamming is eliminated. Excessive wear of moving parts and friction losses are reduced to a minimum. The valve closes drop tight, and is highly efficient and economical.



Chapman Iron Body Non-Slam Tilting Disc Check Valve

MANUFACTURING CO.

MASSACHUSETTS

LINK-BELT EQUIPMENT
for Sewage and Water Treatment Plants

BAR SCREENS
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TRITOR SCREENS
•
GRIT CHAMBER EQUIPMENT
•
MIXING EQUIPMENT
•
STRAIGHTLINE COLLECTORS
(For Rectangular Tanks)
•
CIRCULINE COLLECTORS
(For Center-Feed Round Tanks)
•
SCUM BREAKERS FOR DIGESTION TANKS
(Round or Rectangular)

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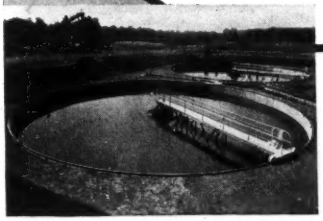
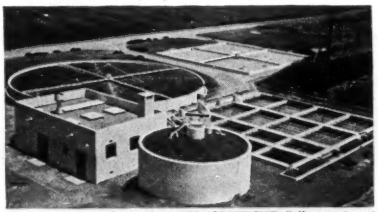


Above: Link-Belt CIRCULINE Collector. It has all the advantages of the STRAIGHTLINE type collector with the added advantage of low cost concrete construction for large tanks.

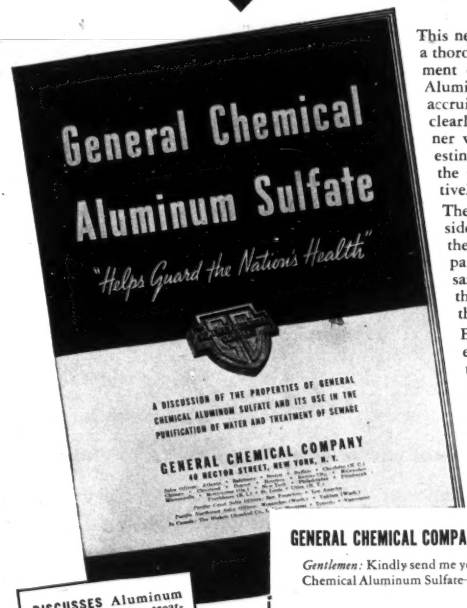


Above: The Link-Belt STRAIGHTLINE Mechanically Cleaned Bar Screen, has spaced parallel bars on which the larger floating solids in incoming sewage collect, and a mechanically operated rake for removal of the accumulating solids, thus assuring an even flow of sewage through the channel. The machine may be set vertically or inclined, and used in small or large plants.

8100

Bio-Filtration plant at Camarillo, Calif., employs STRAIGHTLINE Collectors in settling tanks—one of the eighteen installations of this type now in operation. Rectangular tanks with a ratio of length to width of 4 to 1 or more are particularly suitable for the mixing of the raw and recirculated sewage.

A "DOWN TO EARTH" DISCUSSION ON THE USE OF ALUMINUM SULFATE FOR WATER PURIFICATION AND SEWAGE TREATMENT


General Chemical
Aluminum Sulfate
"Helps Guard the Nation's Health"
A DISCUSSION OF THE PROPERTIES OF GENERAL CHEMICAL ALUMINUM SULFATE AND ITS USE IN THE PURIFICATION OF WATER AND TREATMENT OF SEWAGE
GENERAL CHEMICAL COMPANY
40 RECTOR STREET, NEW YORK, N.Y.

This new General Chemical pamphlet is a thorough-going discussion on the treatment of *both* water and sewage with Aluminum Sulfate and the advantages accruing from its use. The facts are clearly and concisely stated in a manner which the layman will find interesting and understandable, yet which the technical man will find informatively worthwhile.

The pamphlet also takes into consideration the problems concerned in the disposal of industrial wastes—particularly, their relation to public sanitation. Charts and illustrations throughout the booklet supplement the data and add to its value.

Everyone concerned with the operation of either water or sewage treatment plants should read this pamphlet. Particularly pertinent is its discussion on phases of sewage treatment which have become increasingly important in the last few years.

DISCUSSES Aluminum Sulfate in water treatment, removal of tastes and odors; how Aluminum Sulfate precipitates sewage, treating methods and advantages, clarification of industrial wastes. Aluminum Sulfate in drying of sludge, etc.

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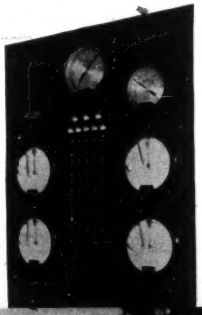
AS WELL AS OUT



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Foxboro flow, level, pressure and temperature controllers and gauges help make possible the remarkable efficiency of operation, while Foxboro electric transmission systems centralize information and control, for the convenience of operators.

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Controlled ACCURACY for RESPONSE

SAVE ON SEWERS

THESE money-saving features of J-M Transite Pipe offer important ways of cutting costs and increasing efficiency on all types of sewer lines. The light weight, long lengths and simple assembly of this modern pipe considerably reduce laying costs. Upkeep is negligible because Transite, made of asbestos and cement, is strong and unusually corrosion-resistant. In many cases, its high flow coefficient and tight joints permit the use of smaller pipe or flatter grades.

If you are planning a new system or modernizing an existing line, you will profit by getting full details on J-M Transite Sewer Pipe. Write for brochure TR-21A. And, for information on J-M Transite Water Pipe, write for brochure TR-11A. Johns-Manville, 22 East 40th Street, New York, N. Y.

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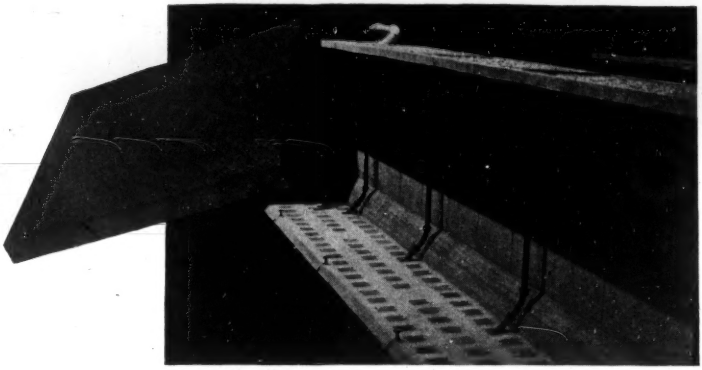
Johns-Manville TRANSITE PIPE

THE MODERN MATERIAL FOR SEWER AND WATER LINES



Selected for Efficient Operation . . .
NORTON POROUS PLATES

IN the modern activated sludge sewage disposal plant at Michigan City, Indiana (design engineer, Charles H. Hurd, Indianapolis), Norton Porous Plates are installed in aluminum plate holders as illustrated. Held in place by bolts, the plates are easily removable for cleaning.

Efficiency of diffuser operation—long life with lowest pressure loss—involves a knowledge of application and manufacture that only experience can supply. Norton experience is founded on fifteen years of manufacture of diffuser mediums for sewage plants backed by over fifty years' experience in the manufacture of ceramic products.

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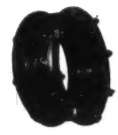

Cross section of Dresser Style 38 Steel Coupling for steel pipe. Style 53 Cast Coupling is the same, except of cast material for cast-iron pipe.

Here are five major reasons why Dresser Couplings are the *practical* answer to your joint problems on sewage lines: (1) Permanent Tightness; (2) Flexibility; (3) Simplicity; (4) Strength; (5) *True* Economy. • Before you install your next air, water, sludge, or outfall line, *learn* MORE about these Dresser advantages. Write today for our 172-page General Catalog No. 36—actually a valuable handbook on pipe joints! DRESSER MFG. COMPANY, BRADFORD, PA.

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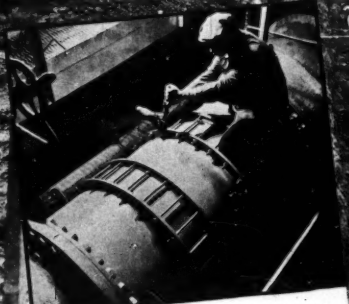
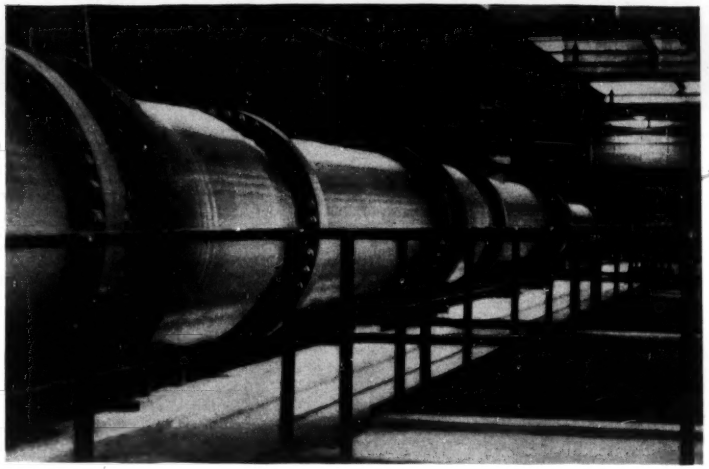


(*Above*) Installing Dresser Couplings on discharge line from raw-sewage pump . . . one of three such lines (48", 42" and 36") at the Blue Plains sewage-treatment plant, Washington, D. C.

(*Right*) 10" cast-iron water line joined with Style 53 Cast Couplings and supplying fresh water to the Washington sewage plant.



Cast iron pipe air line in Main Engine and Blower House at Tallman's Island Treatment Plant, New York City

THE importance of cast iron pipe in sewage works construction began with the development of sewage treatment. Today, more than 90% of the pipe in all treatment plants is cast iron pipe. Now it is also widely used as an efficient, long-lived material for the construction of infiltration-proof sewer mains. Thus cast iron pipe contributes, directly and indirectly, to the economical operation of treatment plants.

Look for the "Q-Check" registered trade mark.
Cast iron pipe is made in diameters from 1¼ to 84 inches.

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THE MODERN MATERIAL FOR SEWERAGE SYSTEMS

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Carbon and Nitrogen Transformations in the Purification of Sewage by the Activated Sludge Process. IV. With a Culture of Sphaerotilus. By M. L. Littman 685

Studies on Activated Sludge Bulking. II. Bulking Induced by Domestic Sewage. By H. Heukelekian and R. S. Ingols 694

Typhoid Bacteria in Sewage and in Sludge. By C. P. Mom and C. O. Schaeffer.... 715

Plant Operation:

Treatment of Supernatant Liquor by Coagulation and Sedimentation. By C. E. Keefer and Herman Kratz, Jr. 738

Sewage Treatment Experiments Conducted at the Los Angeles City Pilot Plant. By H. G. Smith and E. G. Studley 745

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Industrial Wastes:

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Operators' Reports and Suggestions:

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Gadget Contest, Central States Sewage Works Association Meeting in October, 1939.

First Prize. By George Martin 803

Second Prize. By David Backmeyer and W. E. Ross 805

Third Prize. By P. W. Richards 806

Sewage Gas Utilization Systems. By L. L. Langford 807

Editorial:

William Wallace Buffum. By F. W. Mohlman 816

Proceedings of Local Associations:

Michigan Sewage Works Association 818

Oklahoma Water and Sewage Conference 821

California Sewage Works Association 821

New York State Sewage Works Association 824

Reviews and Abstracts:

Wakefield Sewage Works: Notes on Operation. By L. J. Artist 826

Oldham's Reconstructed Sewage Purification Works: Notes on Operation. By J. Taylor 827

Bradford Sewage Works Products 828

Administration of the Public Health (Drainage of Premises) Act, 1937, with Special Reference to Small Authorities. By Reginald Dart 828

Some Comments on Recent Experiments on Activated Sludge. By H. H. Goldthorpe. 829

Observations on Textile Waste Treatment. By C. W. Mengel 830
A Study of Tides and Currents in the Waterways of the Interstate Sanitation District. By Seth G. Hess 831
Public Works Engineers' Yearbook—1940 American Public Works Association. By Albert P. Learned 832
Sewer Rentals 833
Studies on Raritan River Pollution, II, 1937–38. By Willem Rudolfs 833
The System of Activated Sludge-Oxygenated Water. Part IV. Controlled Adsorption. By Denis Dickinson 836
Studies on the Mechanism of Activated Sludge Process in Sewage Purification. By Saburo Shibata 837
Biological Decomposition of Phenol by Means of Activated Sludge with Reference to the Method of Breakdown of its Composition. By Akano Rokuro and Cho Jinnosuke 837
Buffer Values of Sewage During Purification. By Robert S. Ingols and H. Heukelekian 838
Respiratory Quotient of Activated Sludge and of Activated Sludge-Sewage Mixtures. By C. M. Sawyer and M. Starr Nichols 838
Ferric Oxide Hydrosols as Coagulants in Waste Treatment. By A. L. Elder and S. W. Stahl 839
References to Sewage Literature 841
Convention News 844

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Sewage Research

STUDIES OF SEWAGE PURIFICATION

XIII. THE BIOLOGY OF SPHAEROTILUS NATANS KUTZING IN RELATION TO BULKING OF ACTIVATED SLUDGE

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Introduction

The term bulking, as applied to sewage disposal plants is usually definable only in terms of its user. It may mean rising of the sludge blanket until the sludge passes the weir or it may mean great increase in sludge volume accomplished by loss of density. In any case, it means the operator has lost control of the sludge. Its causes are likewise variable and according to the type of bulking; whether we are dealing with a given mass of sludge occupying several times the volume it normally should; or flotation of the floc by gas bubbles; or flotation of the floc by filamentous organisms; or other causes. In one sense, the end result is the same. The effluent is no longer clear but contains objectionable putrescible matter.

Sewage usually contains a variety of filamentous growths ranging from bacteria which develop in masses because of confluent gelatinous sheath-like secretions to ramifying branched mycelia of the true molds. A number of these filamentous organisms have been isolated from sewage and one, *Sphaerotilus natans* Kutzing, has long been associated with bulking. Sometimes it is regarded as the cause of bulking and again as merely being associated with the trouble. Its first description recorded it from "factory water" and it is almost invariably found in polluted waters. Butcher [1] has shown roughly the conditions of its principal occurrence in nature and no sewage polluted stream seems clear of it. Naumann and Wanselin [2] have shown that heavy growths of it in polluted streams are accompanied by oxygen depletion, creation of a septic mud and even obstruction of stream flow. They consider luxuriant growths a basis for legal action.

Sphaerotilus is not normally an abundant growth in an activated sludge chamber, although a few filaments may usually be seen on microscopic examination. But a bulking sludge frequently contains enormous quantities of it. Ardern and Lockett according to Martin [3] had connected bulking with filamentous growths prior to 1922. Hoyle [4] in 1927 reported *Sphaerotilus natans* as the cause of severe bulking. Morgan and Beck [5] reported a similar case in 1928 and Ruchhoft and Watkins [6] studied the *Sphaerotilus* from this bulking sludge in pure

culture. Larsen [7] thinks the fungus merely incidental to bulking and McLachlan [8] questions causation of bulking by the fungus.

Smit [9,10] investigated a filamentous organism which he called the "causative organism" of bulking, although he was not sure it was *Sphaerotilus*. He called it a facultative anaerobe. Naumann [11] showed a huge use of oxygen by *Sphaerotilus* and found a high biochemical oxygen demand for *Sphaerotilus* mud. Ingols and Heukelekian [12] state that bulking "produced by carbohydrates is a direct response of *Sphaerotilus* to a relatively long contact with an available energy food." It appears then that *Sphaerotilus* or organisms akin to it have been shown to be intimately associated with sewage pollution, and have been repeatedly investigated in connection with the bulking of activated sludge.

Isolation and Culture

Because of the association shown above, filamentous growths have been isolated and studies made of these pure cultures at the Stream Pollution Investigations Station, Cincinnati, Ohio. In the course of the work several genera of fungi and fourteen *Sphaerotilus* strains have been obtained in bacteria free culture. *Sphaerotilus* cultures have been obtained from the Station experimental plant, both when bulking and not bulking; from raw Cincinnati sewage; from a sewage polluted stream in a Cincinnati park; from the Ohio River at Cincinnati; and from bulking sludge obtained at the Lima, Ohio, plant.

One significant point is that despite diverse origins, all *Sphaerotilus* strains have behaved alike in culture, and all have shown sufficient variability under experimental conditions, to enable them to be classified at various times as several of the described species of *Sphaerotilus*. We believe all our strains to be *Sphaerotilus natans* Kutzing, and are of the opinion that the species is capable of considerable variation in a changing environment.

The original isolation was obtained from sludge in which only an occasional strand of fungus was to be found. These strands were placed in 8-liter pyrex bottles, containing an enrichment of 1000 p.p.m. of sucrose, and then aerated in the laboratory. Fed by the fill-and-draw method twice a day, such bottles usually showed an abundant growth of *Sphaerotilus* in a few days. From this material small flocs consisting largely of fungus were picked, teased and washed. The usual bacteriological technique was followed, shaking the fungus laden sludge flocs to pieces with glass beads, diluting and plating on nutrient agar, from which sterile colonies were subsequently picked. Fungus flocs were also washed 8 to 10 times in sterile dilution water, then streaked on sterile agar plates. Such flocs usually carried bacteria, but around the margin of the colony long sterile filaments grew out in about 24 hours some of which were cut off and transferred to fresh plates. Agar was first made up according to the formula of Ruchhoft and Watkins,[6] but subsequently only 1.5 per cent filtered sewage agar was used. Overgrowth of plates rarely occurred, the maximum growth being secured

in about 24 hours at 37° C. or 48 hours at room temperature. Overgrowth of plates frequently occurred when certain bacteria were present, especially at 37° C. A filamentous bacterium tentatively identified as *Bacillus mycoides* was often mistaken for *Sphaerotilus* but isolations of the bacterium on sewage agar grew about 4 to 8 times as fast as *Sphaerotilus;* the amount of mycelium formed was greater and its strands had a characteristic whorled appearance to the naked eye. In liquid media it did not form flocs.

Growth of *Sphaerotilus* in liquid media was slower than that of the various bacteria used. Sterile filtered sewage plus dextrose, and synthetic sewage plus dextrose, were good menstruua. In 12 to 48 hours large flocs were formed. The following are the most successful synthetic media:

I. Medium	Mgm.	Synthetic Sewage (S Medium)	Mgm.
$NaNO_3$	25.0	Na_2HPO_4	50.0
$MgSO_4$	10.0	NaCl	15.0
K_2HPO_4	10.0	KCl	7.0
KH_2PO_4	15.0	$CaCl_2$	7.0
$CaCl_2$	45.0	$MgSO_4$	5.0
Peptone	100.0	Peptone	100.0
Dextrose	500.0	Dextrose	500.0
Water	1 liter	Water	1 liter

Many variations of these two media were used, but no great differences in growth were found unless the concentrations of one or more components were raised or lowered greatly.

These concentrations were made up in six liter quantities, in pyrex serum bottles, and sterilized. The mineral salts for preparing the basic media were kept in solutions of convenient strengths. After seeding from a plant or liquid medium, the bottles were continuously aerated through a ball diffuser. No attempt was made to determine the rate of aeration. Incoming air passed through a filter of sterilized cotton, the exit tube was also plugged with a cotton filter. Very little trouble was experienced with contamination. Inoculation from a liquid culture was preferable because inoculations from agar plates often failed to show growth in 24 or 48 hours. But cultures on agar plates remain viable as long as 30 days and on agar slants for even longer periods. Once isolated, *Sphaerotilus* is easy to grow and maintain.

Characteristics and Identification of the Organism

According to Bergey,[13] Kutzing first described the species as "an attached, colorless, thread-like filament, showing false branching." The strands are cylindrical with a thin firm sheath. The sheath is slimy and optically invisible but can be demonstrated in India ink mounts or by several staining methods. The cells, cylindrical or ovoid in longitudinal section, vary in diameter from 1.0 to 3.0 microns, and in length from 3.0 to 8.0 microns, according to age, source (for wild cultures), and culture medium.

The filaments are colorless, but in streams masses of the fungus may be light brown, even with little enmeshed foreign matter. This is probably due to age and dead cells. Single filaments may be several millimeters long, and often many are entwined in a braided manner giving a cord-like appearance. A single strand ends abruptly if free; if attached, in a small disc. Flocs are often 1 cm. in diameter and 5 cm. in length if free floating and are very ragged in contour. When attached, they are long and plumose. Attachment in pure culture depends simply on the degree of agitation of the water by bubbles from the diffuser. Figures 1 and 2 show cultures in serum bottles demonstrating free flocs due to turbulent aeration and attached flocs due to slight aeration.

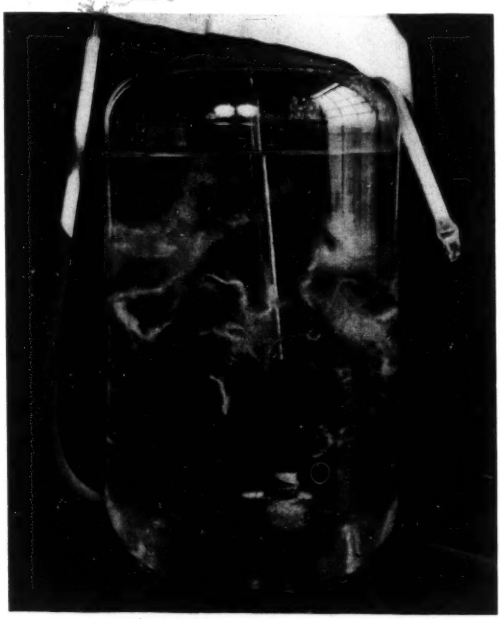


FIG. 1.

The small size precludes determination of much cellular detail. Young cells (Fig. 3) show a relatively homogenous cytoplasm with a few vacuoles. Often a few granules are seen. The vacuoles take up neutral red and are presumably sap vacuoles. Differential staining of granules with haematoxylin and acid stains has not been accomplished. Such chromatin as is present is in very small particles. In old cells the vacuoles become quite large and appear as white spaces after methylene blue, fuchsin or haematoxylin staining. The filament

sheath stains faintly with haematoxylin after Schaudinn's fixative, but not after Flemming with or without acetic acid. It does not stain with methylene blue or fuchsin. The reproductive cells (conidia) which are simply vegetative cells fragmented from a filament, have flagella which are very difficult to stain. We have not been able to demonstrate them with cytological fixatives, but by using air drying fixation followed by Gray's flagella stain they can be shown, as in Fig. 4. Such conidia are then seen to have one to several long flagella, subapically inserted. Cases where there is apparently one flagelleum are probably due to the aggregation of several on air drying. According to Bergey's Manual motile conidia have a clump of flagella near one end.

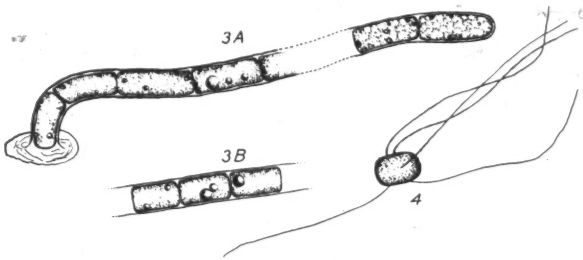
FIG. 2.

These conidia are very active. They swim in only one direction and eventually attach themselves by one end whereupon a long filament grows out from the substrate. Attachment is by the non-flagellated end, for attached conidia still move their free ends for a time. Conidia inoculated into a petri dish of nutrient medium will grow into filaments several millimeters long overnight.

Colonies on sewage or nutrient agar are very delicate, irregular in contour and rarely thick enough for a definite color to be seen. Occasionally on agar slants a gray or white color is seen.

The above morphological observations are largely in accord with those of Smit [10] and our preparations from agar and sludge so closely resemble his that further illustration of this nature seems unnecessary. But some cultural and physiologic differences are noteworthy. The

demonstration of a sheath has been easily accomplished for our cultures. False branching has likewise been frequent, and swarming cells (conidia) have been produced in abundance with all our strains. Smit is not certain his organism was *Sphaerotilus,* whereas ours corresponds closely to the original meager description of Kutzing and there is no doubt but ours is the predominant organism in such well defined cases of bulking as we have seen. The question of attachment seems to depend, as stated above, merely on the degree of agitation in the culture flask. With slight turbulence most of the growth is on the walls of the containing vessel, but with an increase in turbulence most of the growth consists of unattached flocs of all sizes, very ragged and very light. If the air is shut off they settle slowly, but better than the flocs in bulking sludge. The slightest current keeps these flocs in suspension. This explains why *Sphaerotilus* is so objectionable in bulking. Growing out in all directions from sludge flocs, it greatly increases their buoyancy. The fungus also decreases the relative weight of the sludge flocs and assists in trapping air bubbles wherewith to produce a rising sludge.



FIGS. 3 AND 4.

Attempts to grow *Sphaerotilus* on a nidus of other than the flocs of activated sludge have failed. Sawdust, as soon as water logged, settles to the bottom, and has so far failed to provide attachment. Asbestos has likewise failed to act as a center of attachment.

RELATIVE SETTLING RATES OF SOME SLUDGE ORGANISMS

We have found few other fungi to produce bulking experimentally. A branching form, possibly *Gleotrichoides paludosus* Smit, caused bulking in a laboratory sludge. It appeared in May, 1938, in a bottle of activated sludge to which 500 p.p.m. of glucose had been added periodically and gave a heavy growth for several days, during which time the settling power of the sludge was almost completely lost. Eventually the branching fungus was displaced by *Sphaerotilus.* Isolation of it on sewage agar showed a colorless aerial and subsurface mycelium, with moderate fruiting. On peptone agar the subsurface mycelium was yellow brown, the aerial white, and fruiting heavy. Fruiting and growth were heavy in synthetic sewage. Since it appeared only once

in a lengthy series of experiments designed to produce bulking, it has not been further studied.

Several other fungi and organisms have been found to interfere with sludge settling but have not been studied extensively. Under laboratory conditions sludges have developed at times excessive growths of various branching fungi, filamentous bacteria, yeasts and colonial vorticellid ciliates belonging to the genera Epistylis and Opercularia. Table I gives the relative time of settling of some of these in pure culture, using a synthetic sewage. In some cases (yeasts, *B. mycoides*) the effluent is turbid; in others the effluent is clear but contains large masses of suspended matter. This is true of the Phycomycete colonies shown in Fig. 5. In pure culture these form balls as large as marbles in

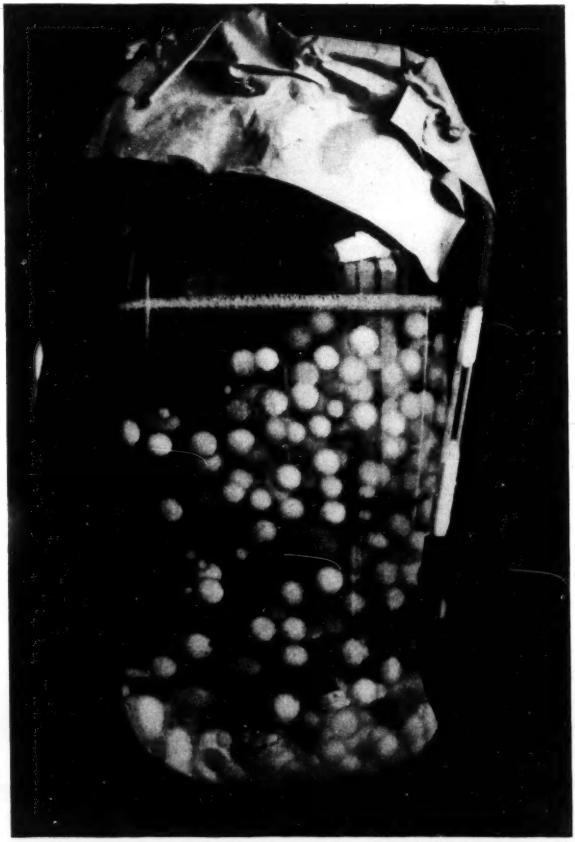


FIG. 5.

aerating bottles of enrichment media and they will settle quickly. But if a current is present they remain in suspension and will pass out in the effluent. The senior author recalls that large colonies of Opercularia were rising and passing over the effluent weir at the Tenafly, N. J., sewage treatment plant some years ago.

Laboratory conditions under which the yeasts, *Bacillus subtilis* and *B. mycoides*, were produced in non-settleable quantities rarely if ever obtain in sewage disposal plants. Table I indicates that organisms other than *Sphaerotilus* will rarely be found associated with or causing bulking.

TABLE I.—*Relative Time of Settling of Certain Sewage Organisms*

	Time Required for:		
	10% Settling	50% Settling	90% Settling
Sludge flocs alone	1 min.	2 min.	3–5 min.
Sphaerotilus on sludge flocs	30 min.	1–2 hours	2–5 hours
Sphaerotilus flocs	30 min.	1–3 hours	3–12 hours
Zoöglea flocs	1 min.	4 min.	7 min.
Penicilium colonies	30 seconds	1 min.	1 min.
Other phycomycete colonies	30 seconds	1 min.	1 min.
Yeast alone	30 min.	12 hours	Indefinite
Bacillus subtilis alone	No settling		
Bacillus mycoides alone	40 min.	6 hours	12 hours

The above rates of settling were determined by allowing the culture under investigation to stand in a 1 liter glass graduate.

SPHAEROTILUS AND BULKING—CAUSE OR EFFECT?

Since bulking of activated sludge may occur in the absence of *Sphaerotilus*, it is not the cause of all bulking. But it is the most abundant organism in most cases of bulking. That it plays a part in this condition is quite evident from a comparison of the settling rate of *Sphaerotilus* infested sludge flocs and sludge flocs with no *Sphaerotilus*. If we could identify and rectify the conditions leading to excessive growth of this fungus, we would undoubtedly cure many cases of bulking. With this in view, many substances were tested to see if they would stimulate the organism to excessive growth. Both mixed cultures and pure cultures were thus tested. The results are shown in Table II.

The following facts are shown by Table II: (1) It is possible to start with a normal activated sludge and by using heavy dosages of disaccharoses to obtain frequently a bulking sludge in which *Sphaerotilus* is very abundant. (2) Sugars will not always produce a heavy growth of *Sphaerotilus*. Sometimes other filamentous fungi grow excessively, or sometimes yeasts. Ruchhoft [14] has also shown that an activated sludge may be conditioned so that it will normally remove up to 1000 p.p.m. of glucose without bulking or unusual growths of organisms. (3) No other substance tested produced heavy growths of *Sphaerotilus* in mixed culture. (4) Both mono- and di-saccharoses produced heavy growths

TABLE II.—*Effects of Various Substances on Growth of Sphaerotilus*

Mixed or Pure Culture	Basic Medium	Substance Added	Range in P.p.m.	Growth of *Sph.*	Settling Quality	Condition of Culture at End
Mixed	Activated sludge	Sucrose	1000–5000—Twice daily	Good	Poor	*Sphaerotilus* dominant
Mixed	Act. sl.	Sucrose	1000—Four times daily	Good	Poor	*Sphaerotilus* replaced
Mixed	Act. sl.	Sucrose	5000—Four times daily	Good	Poor	*Sphaerotilus* replaced
Mixed	Act. sl.	Sucrose	20,000—Once only	Poor	Poor	Yeasts dominant
Mixed	Act. sl.	Glucose	1000–5000—Twice daily	Good	Poor	*Sphaerotilus* dominant
Mixed	Act. sl.	Starch	1000–5000—Twice daily	Poor	Good	Poor
Mixed	Act. sl.	Whole wheat	5000—Once only	Poor	Good	Sludge good
Mixed	Act. sl.	Peptone	100–1000—Once only	Slight	Good	*Sphaerotilus* replaced
Mixed	Act. sl.	Sulfite liquor	5%—Once only	Slight	Good	*Sphaerotilus* replaced
Pure	Sterile raw sewage			Poor	Good	*Sphaerotilus* present
Pure	Sterile raw sewage	Sucrose	1000–10,000—Once only	Good	Poor	*Sphaerotilus* thriving
Pure	Sterile raw sewage	Sucrose	1000—Four times	Good	Poor	*Sphaerotilus* thriving
Pure	Sterile raw sewage	Glucose	1000–10,000—Once only	Good	Poor	*Sphaerotilus* thriving
Pure	Sterile raw sewage	Glucose	1000—Four times daily	Good	Poor	*Sphaerotilus* thriving
Pure	Sterile raw sewage	Maltose	1000–10,000—Once only	Good	Poor	*Sphaerotilus* thriving
Pure	L+100 p.p.m. Peptone	Sucrose	50–1000—Once only	Good	Fair	*Sphaerotilus* thriving
Pure	L+100 p.p.m. Peptone	Sucrose	10,000–60,000—Once only	Fair	No growth at 60,000	
Pure	L+100 p.p.m. Peptone	Glucose	50–1000—Once only	Good	Fair	*Sphaerotilus* thriving
Pure	L+100 p.p.m. Peptone	Glucose	10,000–60,000—Once only	Fair	No growth at 60,000	
Pure	L+100 p.p.m. Peptone	Maltose	50–10,000—Once only	Good	Fair	*Sphaerotilus* thriving
Pure	L+100 p.p.m. Peptone	Lactose	50–10,000—Once only	Good	Fair	*Sphaerotilus* thriving
Pure	L+100 p.p.m. Peptone	Glycerol	50–1000—Once only	None		
Pure	L+100 p.p.m. Peptone	Glycerol	50–1000—Once only	None		
Pure	L+100 p.p.m. Peptone	Whole wheat	100–40,000—Once only	Poor		
Pure	L+100 p.p.m. Peptone	White flour	1000–5000—Once only	None		

TABLE II.—*Continued*

Mixed or Pure Culture	Basic Medium	Substance Added	Range in P.p.m.	Growth of *Sph.*	Settling Quality	Condition of Culture at End
Pure	L+100 p.p.m. Peptone	Laundry starch	100–5000—Once only	None		
Pure	L-6	Laundry soap	50–200—Once only	Good		*Sphaerotilus* thriving
Pure	L	Sodium oleate	50–1000—Once only	None		
Pure	L	Sodium stearate	50–1000—Once only	None		
Pure	L	Oleic acid	50–1000—Once only	None		
Pure	L	Stearic acid	50–1000—Once only	None		
Pure	L	Peptone	50–1000—Once only	Fair	Fair	*Sphaerotilus* thriving
Pure	L	Peptone	1000–30,000—Once only	Poor to none		
Pure	L	Meat extract	500–1000—Once only	Poor to none		
Pure	L-6	NaCl	5–200—Once only	Variable to poor		
Pure	L-6	Sulfite liquor	5%—Once only	Good		
Pure	L	Ammonium glycero-phosphate	100–1000—Once only	Slight		
Pure	L, dextrose	Urea	50–100—Once only	Good		
Pure	Synthetic	Dextrose 500 p.p.m.	Peptone 100 p.p.m.—Once only	Good	Fair	
Pure	Synthetic	Dextrose 500 p.p.m.		None		
Pure	Synthetic	Dextrose 500 p.p.m.	Urea 100 p.p.m.—Once only	Fair		
Pure	Synthetic	Dextrose 1000 p.p.m.	Glycerine 250 p.p.m.—Once only	Slight		
Pure	Synthetic	Dextrose 1000 p.p.m.	$NaNO_3$ 112 p.p.m.—Once only	Fair		
Pure	Synthetic	Dextrose 500 p.p.m.	l-tyrosine 100 p.p.m.—Once only	Slight		
Pure	Synthetic	Dextrose 500 p.p.m.	l-cystine 100 p.p.m.—Once only	Slight		
Pure	Synthetic	Dextrose 500 p.p.m.	l-asparagine 100 p.p.m.—Once only	Good		
Pure	Synthetic	Dextrose 500 p.p.m.	l-leucine 50 p.p.m.—Once only	Slight		

TABLE II.—*Continued*

Mixed or Pure Culture	Basic Medium	Substance Added	Range in P.p.m.	Growth of *Sph.*	Settling Quality	Condition of Culture at End
Pure	Synthetic	Dextrose 500 p.p.m.	dl-alanine 100 p.p.m.— Once only	Good		
Pure	Synthetic	Dextrose 500 p.p.m.	d-glutamic acid 100 p.p.m.— Once only	Very poor		
Pure	Synthetic	Dextrose 500 p.p.m.	Sarcosine 100 p.p.m.— Once only	Slight		
Pure	Synthetic	Dextrose 500 p.p.m.	Creatine 100 p.p.m.— Once only	Very poor		
Pure	Synthetic	Dextrose 500 p.p.m.	Sodium glycholate 100 p.p.m.— Once only	Slight		
Pure	Synthetic	Dextrose 500 p.p.m.	Globulin 100 p.p.m.— Once only	None		
Pure	Synthetic	Dextrose 500 p.p.m.	Isatin 100 p.p.m.— Once only	None		
Pure	Synthetic	Dextrose 500 p.p.m.	Acetontrile 100 p.p.m.— Once only	None		
Pure	Synthetic	Dextrose 500 p.p.m.	dl-alanin 100 p.p.m.— Once only	None		
Pure	Synthetic	Dextrose 500 p.p.m.	Na-gluconate 500 p.p.m.— Once only	Fair		

Medium L is only mineral salts and water.
Medium L-6 is the same, with dextrose and peptone added.
Medium synthetic is only organic salts and water, but contains no nitrate.

of *Sphaerotilus* in pure culture. (5) No polysaccharose gave good growths in pure culture. (6) Both organic and inorganic sources of nitrogen were utilized. (7) Peptone, alanin and asparagin were the only nitrogenous substances giving a definite stimulus to growth in pure culture. (8) Increasing the inorganic salt content from about 100 p.p.m. to about 300 p.p.m. did not materially affect growth, but above 300 p.p.m. a limiting effect on growth set in. (9) We have not been able to produce bulking experimentally without using high concentrations of substances not usually found in sewage. (10) We have not been able to produce growths comparable to those in polluted streams by using river water and adding small amounts of growth stimulating substances.

The experimental work represented by Table II suggests that excessive growth and consequent trouble by this organism is not usually

due to growth promoting substances present in sewage. Exceptions are always possible, as in the trouble experienced by Morgan and Beck [5] at Maywood. It appears more probable that some feature of plant operation is likely to be the cause. In the case of a disposal plant troubled with bulking, a quick microscopic examination of the sludge, followed by a test for sugars either in raw sewage or sludge, might quickly determine if the cause should be sought in the sewage or in plant operation.

Specific Nutritive Requirements

A basic medium was made up containing:

$NaNO_3$	25 mgm.	$CaCl_2$	45 mgm.
K_2HPO_4	5 mgm.	Dextrose	1000 mgm.
KH_2PO_4	5 mgm.	Distilled water	1 liter
$MgSO_4$	10 mgm.		

This medium gave a slight growth, although there was a great excess of sugar. It was then varied by leaving out one after another of the mineral salts, and in each case no growth resulted. Other variations were to leave out a salt, increasing the concentration of others. This again failed, except for the mono- and di-basic potassium phosphate; 10 p.p.m. of either would support slight growth in the absence of the other provided the remaining three salts were present. The minimal growth threshold seems to be about 5 p.p.m. each of $NaNO_3$, KH_2PO_4, K_2HPO_4, $MgSO_4$ and $CaCl_2$, plus dextrose. Leaving out any one of the salts at this concentration stopped growth, and living *Sphaerotilus* could not be recovered from such a medium after 3 days' aeration. Any variation of this medium, using less than the eleven chemical elements contained therein appeared not to support growth.

Maximum growth of the fungus appears possible on as little as 200 p.p.m. of mineral salts. Increasing salts beyond this, either with or without increasing the nitrogen and sugar, failed to increase the amount of fungus produced. The cell wall or colony sheath, and the protoplasm of this organism apparently contain very little mineral matter.

Under laboratory conditions, the greatest food requirements necessary to heavy growth seem to be sugars and organic nitrogen. If the synthetic sewage medium is made up with dextrose and no nitrogen, growth is not expected and does not occur; if glycine is substituted for the dextrose no growth occurs; if peptone is substituted for the dextrose, poor growth results; but if both dextrose and peptone are present, heavy growth results, and some growth results if almost any combination of these two is used.

Nitrogen requirements of *Sphaerotilus* are also very general. Table III shows the sources of nitrogen which were tried and the relative growth produced. It will be noted that the best growths were secured from organic sources—alanin, asparagin and peptone, but fair growths were also secured on the inorganic salts. This fungus thus presents a broad adaptability in its nutritive requirements and this characteristic is probably an important factor in making it such a successful inhabitant

of rivers and sewage disposal plants. In addition to its wide nutritive range, it exhibits a relatively wide range of pH tolerance, growing between 5.5 and 8.0. It grows well in a solution of 200 p.p.m. of laundry soap, but only if dextrose and peptone are present; *i.e.* it does not use soap. Agar plates inoculated with *Sphaerotilus* then placed in Novy jars will not grow if the air is exhausted; if nitrogen is substituted; or if CO_2 is substituted. No growth results in bottles into which nitrogen is bubbled, and thriving cultures are soon killed if nitrogen is substituted for the air. The same is true for methane. Evidently the plant is an aerobe—but a thriving culture in a substrate with abundant protein or peptone has a characteristic odor which our chemists [14] have stated is due to primary amines. The organism thus dissimilates proteins or peptones in an anaerobic manner even in the presence of abundant oxygen. The oxidative processes of *Sphaerotilus* in relation to oxygen, sugar and nitrogenous matter, and the building of protoplasm and cell walls (fungus cellulose) will be discussed in another paper.

TABLE III.—*Forms of Nitrogen Used by Sphaerotilus*

Basic Medium	Form of Nitrogen	Growth
Synthetic sewage (S med.)	Nitrites	None
Synthetic sewage (S med.)	Nitrates	Fair
Synthetic sewage (S med.)	Ammonium salts	Fair
Synthetic sewage (S med.)	Urea	Fair
Synthetic sewage (S med.)	Glycine	Poor
Synthetic sewage (S med.)	l-tyrosine	Poor
Synthetic sewage (S med.)	l-cystine	Poor
Synthetic sewage (S med.)	l-leucine	Poor
Synthetic sewage (S med.)	dl-alanine	Good
Synthetic sewage (S med.)	d-glutamic acid	Poor
Synthetic sewage (S med.)	Isatin	None
Synthetic sewage (S med.)	l-asparagin	Good
Synthetic sewage (S med.)	Sarcosin	Poor
Synthetic sewage (S med.)	Peptone	Good
Synthetic sewage (S med.)	Gelatin	None
Synthetic sewage (S med.)	Autoclaved wheat	None

CONTROL OF *Sphaerotilus*

Inasmuch as the organism grows excessively because of some substance in sewage or some defect in plant operation, knowledge of the cause and control of growth is useful, both for prevention and cure of the disease. Smith and Purdy [15] suggested chlorine for control of growth and it has since been extensively used with good results. Laboratory experiments were carried out by us to find possibly some specific killing agent for *Sphaerotilus*. The results are shown in Table IV. None of the substances tried seem to be specific, although silver nitrate and some of the dyes are toxic at low concentrations and malachite green, 5 p.p.m., is not toxic to a number of other organisms of the activated sludge community. Present cost of this dye would make its use prohibitive, in comparison to chlorine; in fact, the relatively low cost of chlorine has discouraged any extensive search for killing agents.

The method of using the chlorine depends largely on the individual plant, but it seems probable that chlorination of the returned sludge is most feasible.

TABLE IV.—*Effects of Possible Toxic Agents on Growth of Sphaerotilus*

Culture	Toxic Agent	Method of Application	Effect
Mixed act. sludge	Toluene vapor	Bubbled into normal sludge	None
Mixed act. sludge, bulking	Toluene vapor	Bubbled into bulking sludge	None
Mixed act. sludge, bulking	Chloroform	Bubbled into bulking sludge	Toxic
L-6, heavy culture	Chlorine, as H. T. H.	Dosed to a residual of 0.5 p.p.m.	Toxic
L-6, inoculated with *Sphaerotilus*	Chlorine added	0.5 to 3.0 p.p.m. before inoculation	No growth
L-6, heavy culture	$AgNO_3$	0.5 to 2.5 p.p.m. added to heavy culture	Toxic
L-6, inoculated with *Sphaerotilus*	$AgNO_3$	0.5 to 2.5 p.p.m. before inoculation	No growth
Mixed act. sludge, good culture	$AgNO_3$	0.5 to 2.5 p.p.m. to heavy culture	Toxic at 2 p.p.m.
Mixed act. sludge, good culture	Phenol	1.0 p.p.m. to heavy culture	No effect
Mixed act. sludge, good culture	Phenol	5.0 to 50 p.p.m. to heavy culture	Toxic, variable
L-6, heavy culture	Phenol	1.0 p.p.m. to heavy culture	No effect
L-6, heavy culture	Phenol	5.0 p.p.m. to heavy culture	Toxic
Mixed act. sludge, good culture	Acetic acid	50 p.p.m. to heavy culture	Toxic
Mixed act. sludge, good culture	Citric acid	100 to 1000 p.p.m. to heavy culture	*Sphaerotilus* replaced
Mixed act. sludge, good culture	Lactic acid	100 to 1000 p.p.m. to heavy culture	*Sphaerotilus* replaced
Mixed act. sludge, good culture	Brilliant green	5 to 20 p.p.m. to heavy culture	Toxic at 5 p.p.m.
Mixed act. sludge, good culture	Fast green	5 to 25 p.p.m. to heavy culture	Non-toxic
Mixed act. sludge, good culture	Malachite green	5 to 10 p.p.m. to heavy culture	Toxic at 5 p.p.m.
Mixed act. sludge, good culture	Janus green	5 to 20 p.p.m. to heavy culture	Toxic at 20 p.p.m.
Mixed act. sludge, good culture	Eosin W	5 to 50 p.p.m. to heavy culture	Variable
Mixed act. sludge, good culture	Methylene blue	5 to 20 p.p.m. to heavy culture	Toxic at 20 p.p.m.
Mixed act. sludge, good culture	Gentian violet	5 to 15 p.p.m. to heavy culture	Toxic at 10 p.p.m.
Mixed act. sludge, good culture	Uranin	5 to 200 p.p.m. to heavy culture	Non-toxic

DISCUSSION

We have shown herein that the production of a bulking sludge by heavy dosages of sugars is relatively easy. Other substances have practically failed to produce such results.

Associated with bulking in most cases, is the filamentous organism *Sphaerotilus natans* Kutzing. Repeated isolations have failed to produce but a single type of this organism. Butcher [1] studying polluted

streams, called the species natans of Kutzing var. typica, and added four other varieties, but was of the opinion they were ecologic varieties. Organisms taken in the field by us have shown some variation, but when we have isolated them and grown them under similar conditions, all have behaved alike so it seems probable the term "ecologic varieties" is well chosen. Smit [16] called his organism a *Sphaerotilus*, but noted some differences from the usual definition and reserved his opinion as to definitely placing it. Elsewhere [16] he described what is presumably his original organism as *Sph. paludosus*, without pseudo-dichotomous branching and no motile cells. Since all strains of our organism exhibit pseudo-dichotomous branching and form motile reproductive cells abundantly, it seems probable that our organism is *Sphaerotilus natans* Kutzing and such cases of bulking as we have studied have been associated with *Sphaerotilus natans*. We have isolated an organism which agrees with Smit's *Sphaerotilus paludosus* morphologically, but so far it has refused to grow abundantly in the several synthetic media in use. Beger [17] found *Sphaerotilus natans* in activated sludge, but reported a new species which he named tenuis as more abundant. His description is very meager. He did not study pure culture.

If Beger's species is valid, there appears to be five recognized species of *Sphaerotilus; S. tenuis* Beger; *S. paludosus* Smit; *S. natans* Kutzing; *S. dichotomus* (Cohn) Migula; and *S. fluitans* (Migula) Schikora. Our cultures illustrate the described morphological characteristics of *Sphaerotilus natans* very well, but not the nutritive characteristics. On the other hand, our organism has the same nutritive characteristics as *Sphaerotilus dichotomus*. *Sphaerotilus dichotomus* has been accepted by some workers as *Cladothrix dichotoma* Cohn. It is certainly closely related to *Sphaerotilus natans*, but we have been unable to isolate any organism close to *Sphaerotilus natans* which exhibits dichotomous branching. In our opinion *Sphaerotilus fluitans* needs more investigation before its inclusion as a separate species, and it appears that the whole group might be carefully investigated especially with regard to cultural characteristics.

Conclusions

It is possible to produce experimental bulking of activated sludge, such as occurs in sewage disposal plants by heavy dosages of sugars, or mixtures of nitrogenous and carbonaceous compounds. Such bulking may be associated with several organisms, but usually the predominant organism is the filamentous bacterium *Sphaerotilus natans* Kutzing.

Only one species has been isolated in this laboratory, and its cultural characteristics have been constant, although field collections from which some of these isolations were made have shown morphologic differences.

The organism has been shown to give abundant growth on solutions of sugar if a suitable source of nitrogen is present. Inorganic nitrogen is readily used, but only two of several amino acids, alanin and aspara-

gin, have given good growth. Peptone has proved a good source of nitrogen.

No substance common, or apt to occur normally in sewage, has been found which stimulates to excessive growth.

A number of other fungi have been grown in pure culture but have not shown such poor settling qualities as *Sphaerotilus* and only yeasts, *Bacillus subtilis* and *Bacillus mycoides* have shown a very slow settling rate.

Toxic effects toward *Sphaerotilus* of a number of substances have been investigated. No toxic substance cheaper or more available than chlorine has been found.

BIBLIOGRAPHY

1. R. W. Butcher. Contribution to our Knowledge of the Ecology of Sewage Fungus. *Trans. Brit. Myc. Soc.*, **17**, 112–124 (1932).
2. Einar Naumann and John Wanselin. Uber Frielandversuche zur Ermittlung des Sauerstoff-verbrauchs von Sphaerotilus-Aufwuchs. *Bot. Notizer*, **1/2**, 141–144 (1934).
3. A. J. Martin. *The Activated Sludge Process*, XIV, p. 415. MacDonald and Evans, London, (1927).
4. W. H. Hoyle. Part of the Discussion on the Operation of Activated Sludge Plants by H. T. Calvert. *Proc. Assn. Mgrs. Sew. Disposal Wks.*, pp. 33–45 (1927).
5. E. H. Morgan and A. J. Beck. Carbohydrate Wastes Stimulate Growth of Undesirable Filamentous Organisms in Activated Sludge. THIS JOURNAL, **1**, 46–51 (1928).
6. C. C. Ruchhoft and J. H. Watkins. Bacteriological Isolation and Study of the Filamentous Organisms in the Activated Sludge of the DesPlaines River Sewage Treatment Works. *Ibid.*, **1**, 52–58 (1928).
7. W. A. Larsen. Bulking of Activated Sludge. *Mun. San.*, **7**, 52–54 and 64 (1936).
8. J. A. McLachlan. The Settlement and Rising of Activated Sludge. *The Surveyor*, **90**, 2320 (1936).
9. Jan Smit. A Study of the Conditions Favoring the Bulking of Activated Sludge. THIS JOURNAL, **4**, 960–972 (1932).
10. Jan Smit. Bulking of Activated Sludge. II. On the Causative Organisms. *Ibid.*, **6**, 1041–1053 (1934).
11. Einar, Naumann. Uber die Begutachtung des Aufwuchses von Sphaerotilus natans Kutzing. *Arch. f. Hydrobiol.*, **25**, 407–422 (1933).
12. R. S. Ingols and H. Heukelekian. Studies on Activated Sludge Bulking. I. Bulking of Activated Sludge by Means of Carbohydrates. THIS JOURNAL, **11**, 927–945 (1939).
13. D. H. Bergey. Manual of Determinative Bacteriology, 5th Ed., xi + 1032 pp. Williams and Wilkins, Baltimore (1939).
14. C. C. Ruchhoft. Unpublished data, 1940.
15. Russell S. Smith and W. C. Purdy. Studies of Sewage Purification. IV. The Use of Chlorine for the Correction of Sludge Bulking in the Activated Sludge Process. THIS JOURNAL, **8**, 223–230 (1936).
16. Jan Smit. Uber die Ursachen des Aufblahens von Belebtschlamn. *Arch. Mikrobiol.*, **5**, 550–560 (1934).
17. Herbert Beger. Biologische Reinigung in dunner Abwasserschicht. *Beihefte z. Ges.-Ingenieur*, **2**, 1–19 (1935).

CARBON AND NITROGEN TRANSFORMATIONS IN THE PURIFICATION OF SEWAGE BY THE ACTIVATED SLUDGE PROCESS. IV. WITH A CULTURE OF SPHAEROTILUS*

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In earlier work it was demonstrated [1] that pure culture sludge composed of the organism *Zoogloea ramigera* could not be caused to bulk by environmental conditions which produced severe bulking in natural activated sludges. This fact appeared to indicate that certain types of bulking of activated sludge were associated with the overgrowth of other organisms, notable filamentous, to produce a sludge occupying a much greater volume than the organism *Zoogloea ramigera* which forms the primary floc of activated sludge.

A culture of *Sphaerotilus* sludge was produced to study the carbon and nitrogen transformations and general behavior of this organism for the evaluation of its role in the purification of polluted waters brought about by natural activated sludges.

Method

A natural activated sludge was fed excessive carbohydrates and limited nitrogen to produce bulking. After two days, the white cottony filaments of *Sphaerotilus* appeared in the bulky sludge. These flocs were teased from the brown activated sludge flocs and shaken in distilled water to cause fragmentation. The distilled water suspension of *Sphaerotilus* was plated out on nutrient agar containing 1000 p.p.m. glucose and 1000 p.p.m. starch. After incubation at 32° C. the characteristic colonies of *Sphaerotilus*, described by Smit [2] were easily detected. In order to insure purity of culture, three re-platings were made through nutrient agar which was enriched with glucose and starch. Morphological and cultural characteristic of the culture indicated that the organism obtained was identical with that of Smit.

Colonies of *Sphaerotilus* on sewage agar were small, but reached a diameter as great as 8–12 mm. on nutrient agar containing glucose and starch. In nutrient broth containing these carbohydrates only short fragmented threads of the organism developed. This was also in accord with the observation of Smit. In dilute nutrient broths and in sewage containing 1000 p.p.m. glucose the culture formed longer threads similar to those in bulky natural activated sludges. Attempts to build up a culture sludge of *Sphaerotilus* in sterile sewage alone met with failure. Analagous behavior of *Sphaerotilus* was also observed by Smit and Purdy.[3] However, growth of the fungus in sterile sewage containing glucose and starch was fairly rapid.

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In order to produce a large amount of *Sphaerotilus* sludge, the culture was first grown in large flasks containing nutrient broth enriched with glucose and starch.

The cellular masses were then transferred to sterile sewage and aerated for several days with daily transfers. Sterile aeration apparatus used for this culture work was the same as previously described.[1] The floc formed by *Sphaerotilus* was white and fluffy and quite different from the compact zoogleal sludge formed by *Zooglea ramigera*. The volume occupied by the *Sphaerotilus* sludge was approximately three times that occupied by the *Zooglea ramigera* sludge. The *Sphaerotilus* sludge, S–1, was used in a sufficient concentration to provide six liters of sludge-sewage mixtures containing 757 p.p.m. suspended sludge solids. The mixture was aerated in flasks fitted with CO_2 — free air supply identical with apparatus outlined in previous work.[4]

Results

Turbidity and B.O.D. removal from the sewage by the *Sphaerotilus* sludge is presented in Table I. In four hours' aeration approximately 46 per cent of the initial turbidity was removed and 56 per cent of the B.O.D. Over-aeration to 24 hours increased the turbidity of the settled liquor but not the B.O.D.

Table I.—*Turbidity and B.O.D. Reduction of Sterile Sewage by a Culture Sludge of Sphaerotilus (Solids Concentration 757 p.p.m.)*

Aeration Hours	Turbidity P.p.m.	5-Day B.O.D. P.p.m.
0	118	86
1	112	81
2	86	60
3	78	43
4	64	38
24	88	37

Carbon Transformations

The progressive changes with aeration of the carbon content of the fungus sludge, settled liquor and Seitz filtrate are given in Table II. The carbon balance of the entire mixture was fairly constant with an average experimental error of + 1.0 per cent.

As was the case in zoogloea sludges and in natural activated sludge, carbon in the *Sphaerotilus* sludge was entirely organic in nature. Aeration of the sludge with sewage produced an increase in the amount of organic carbon in the sludge floc, while approximately one-third of the organic carbon in the settled liquor was removed. Part of the removal of organic carbon from the settled liquor was due to the loss of suspended organic carbon and partly to depletion of soluble organic carbon. Carbon dioxide production was quite high and increased markedly within the purification period of four hours. Over-aeration of the mixture produced a large loss of carbon from the sludge as carbon dioxide. There was also an increase in the amount of suspended organic carbon in the settled liquor.

TABLE II.—*Carbon Transformations in the Purification of Sterile Sewage by Aeration with a Sludge of Sphaerotilus (Solids Concentration, 757 P.p.m.)*

Aeration	Material	Inorganic Carbon	Organic Carbon	CO_2—Carbon Liberated		Total Carbon	Experimental Error
				at each interval	per hour		
Hours		P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	Per Cent
0	Settled Liquor	4.6	91.0	0	0	95.6	
	Solution (Seitz)	4.6	32.0				
	Suspension	0	59.0				
	Sludge	0	272.6			272.6	
	Total Carbon					368.2	
1	Settled Liquor	6.3	87.2	3.5	3.5	97.0	
	Solution (Seitz)	6.2	29.1				
	Suspension	0.1	58.1				
	Sludge	0	274.3			274.3	
	Total Carbon					371.3	+0.8
2	Settled Liquor	5.5	81.5	4.4	4.4	91.4	
	Solution (Seitz)	5.5	27.5				
	Suspension	0	54.0				
	Sludge	0	281.3			281.3	
	Total Carbon					372.7	+1.2
3	Settled Liquor	8.3	69.5	11.5	11.5	89.3	
	Solution (Seitz)	8.1	12.5				
	Suspension	0.2	47.0				
	Sludge	0	284.4			284.4	
	Total Carbon					373.7	+1.5
4	Settled Liquor	7.1	60.3	16.7	16.7	84.1	
	Solution (Seitz)	7.1	13.2				
	Suspension	0	47.1				
	Sludge	0	285.0			285.0	
	Total Carbon					369.1	+0.2
24	Settled Liquor	4.6	80.2	91.6	4.6	176.4	
	Solution (Seitz)	4.5	15.3				
	Suspension	0.1	64.9				
	Sludge	0	197.7			197.7	
	Total Carbon					374.1	+1.6
	Average experimental error						+1.0

All calculations on basis of one liter of mixture.

Average hourly rate of carbon dioxide evolution was 7.03 milligrams/1000 p.p.m. *Sphaerotilus* sludge solids/hour. The basal rate of carbon dioxide evolution calculated from the fourth to 24th hour of aeration was 6.05 milligrams/1000 p.p.m. solids/hour.

TABLE III.—*Nitrogen Transformations in the Purification of Sterile Sewage by Aeration with Culture Sludge of Sphaerotilus (Solids Concentration, 757 P.p.m.)*

Aeration	Material	Nitrate Nitrogen	Ammonia Nitrogen	Organic Nitrogen	Total Nitrogen	Experimental Error
Hours		P.p.m.	P.p.m.	P.p.m.	P.p.m.	Per Cent
0	Settled Liquor	0.1	18.0	6.2	24.3	
	Solution (Seitz)	0.1	18.0	0.3		
	Suspension	0	0	5.9		
	Sludge	0	0	62.0	62.0	
	Total Nitrogen				86.3	
1	Settled Liquor	0.1	13.2	5.4	18.7	
	Solution (Seitz)	0.1	13.2	1.5		
	Suspension	0	0	3.9		
	Sludge	0	0	70.8	70.8	
	Total Nitrogen				89.5	+3.7
2	Settled Liquor	0.1	10.2	7.3	17.6	
	Solution (Seitz)	0.1	10.2	1.2		
	Suspension	0	0	5.9		
	Sludge	0	0	73.1	73.1	
	Total Nitrogen				90.7	+5.2
3	Settled Liquor	0.1	12.2	4.8	17.1	
	Solution (Seitz)	0.1	12.3	2.0		
	Suspension	0	−0.1	2.8		
	Sludge	0	0	69.5	69.5	
	Total Nitrogen				86.6	+0.3
4	Settled Liquor	0.1	14.0	5.3	19.4	
	Solution (Seitz)	0.1	14.2	2.0		
	Suspension	0	−0.2	3.3		
	Sludge	0	0	67.5	67.5	
	Total Nitrogen				86.9	+0.6
24	Settled Liquor	0.1	27.8	8.2	35.6	
	Solution	0.1	27.8	6.1		
	Suspension	0	0	2.1		
	Sludge	0	0	50.3	50.3	
	Total Nitrogen				85.9	−0.4
	Average experimental error					+1.9

Nitrogen Transformations

In Table III are recorded the nitrogen changes which occurred during aeration in the different sludge-sewage fractions. Average experimental error of the nitrogen balance was + 1.9 per cent. Nitrates were not formed. Ammonia nitrogen decreased during the purification period while organic nitrogen in the sludge increased an equivalent amount. Adsorption of organic nitrogenous matter did not occur, as this fraction decreased little during aeration. There was, however, a quantitative conversion of suspended organic nitrogen to soluble organic nitrogen from the initial to 24th hour of aeration. Over-aeration of the sludge produced a liberation of ammonia nitrogen which accumulated in the settled liquor.

Changes in the solids of the sludge, carbon and nitrogen percentages and C/N ratio are found in Table IV. Organic matter rose slightly with aeration. The per cent organic matter content of *Sphaerotilus* sludge was approximately the same as that of the zoogleal culture

Table IV.—*Changes in Solids, Carbon and Nitrogen Content of Culture Sludge of Sphaerotilus Upon Aeration with Sterile Sewage (Initial Solids Concentration, 757 P.p.m.)*

Aeration	Total Solids	Ash	Organic Solids	Organic Solids	Carbon	Nitrogen	Carbon	Nitrogen	C/N
Hours	P.p.m.	P.p.m.	P.p.m.	Per Cent	P.p.m.	P.p.m.	Per Cent	Per Cent	
0	757.6	95.6	662.0	87.5	272.6	62.0	36.3	8.2	4.4/1
1	782.3	99.3	683.0	87.5	274.3	70.8	35.2	9.1	3.9/1
2	789.0	103.0	686.0	87.0	281.3	73.1	35.5	9.3	3.8/1
3	780.2	90.1	690.1	88.4	284.4	69.5	36.5	8.9	4.1/1
4	771.6	91.6	680.0	89.5	285.0	67.5	37.0	8.8	4.2/1
24	618.0	75.0	543.0	87.9	197.0	50.3	32.0	8.1	3.9/1

sludge. The *Sphaerotilus* sludge, however, possessed an average carbon content of 35 per cent while that of the zoogleal sludge was approximately 45 per cent. The higher carbon content of the zoogleal sludge is probably due to the large amount of capsular material present in the zoogleal flocs which give them their characteristic appearance, and to the absence of large quantities of gelatinous material in the fungus sludge. The *Sphaerotilus* sludge possessed approximately the same nitrogen content as the zoogleal sludges but had a lower C/N ratio.

Discussion

Bulky activated sludges overgrown with *Sphaerotilus* are known to clarify sewages. The *Sphaerotilus* sludge produced in the laboratory removed 46 per cent turbidity and 50 per cent B.O.D. from sewage in four hours' aeration. Microscopic examination of the sludge at the end of the aeration period and inoculation into nutrient broth confirmed the purity of the culture.

The clarifying and purifying activity of a sewage clarifying organism is dependent upon the ability of the organism to form flocculent

gelatinous masses which take up dissolved suspended impurities and settle fairly rapidly and compactly. The sludge masses produced by *Sphaerotilus* were composed of threads of the organisms, were not gelatinous however, and when viewed under the microscope did not have the characteristic zoogleal appearance which sludges of *Zooglea ramigera* and natural activated sludges possess. The sludge developed by *Sphaerotilus* is ordinarily composed of white flocculent but fluffy masses, of short tangled threads. Under conditions of constant agitation, the strands of *Sphaerotilus* are not very long, may form balls, but are of

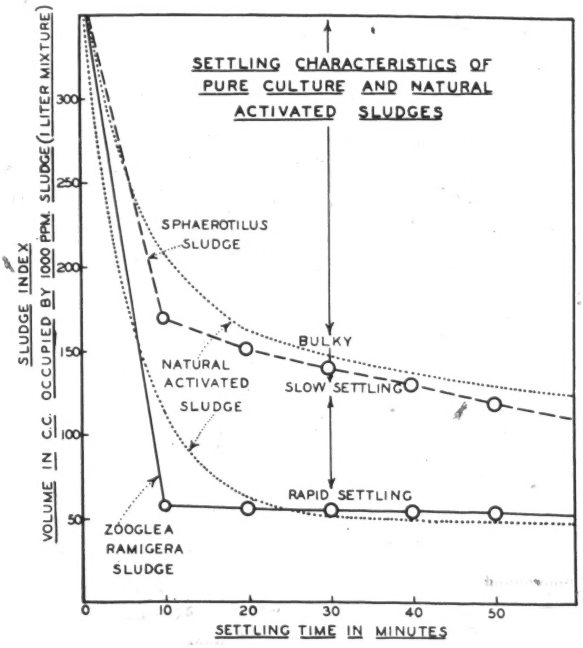

FIG. 1.

sufficient length to produce a fluffy sludge occupying a large volume and possessing a high sludge index. Sludges developed by *Sphaerotilus* and other filamentous organisms can therefore be considered to be normally bulky when compared to either rapid settling natural activated sludge or zoogleal sludge. An example of the settling volumes of equal quantities of *Sphaerotilus* sludge and that of *Zooglea ramigera* is shown in Fig. 1. After thirty minutes settling, the *Sphaerotilus* sludge was found to occupy approximately three times the volume of *Zooglea ramigera* sludge. The sludge index of *Sphaerotilus*

was 15 and of the zoogleal sludge 54. This index value of the *Sphaerotilus* sludge is relatively low when compared with indices of severely bulking natural activated sludge. This is explained by the fact that the fungus sludge studied possessed only short threads while older sludges of this organism are constituted of longer threads and possess higher indices. The statement was made in a previous paper [1] that "the phenomenon of bulking of activated sludge was not concerned with a change in the zoogleal floc of activated sludge." This points at once to the importance in the bulking phenomenon of filamentous organisms such as *Sphaerotilus* which are stimulated by excess carbohydrates and other environmental conditions to overgrow natural activated sludge and produce bulking. In view of the further evidence it appears reasonable that the overgrowth of the sludge by filamentous organisms, particularly *Sphaerotilus,* results in poorer settling, fluffy floc.

Carbon dioxide production by *Sphaerotilus* sludge was rather high. The average rate of CO_2 release over the 24 hour period was 7.03 milligrams/1000 p.p.m. solids/hour, while the basal rate of CO_2 release from the sludge itself (from 4th to 24th hour of aeration) was 6.03 milligrams. The basal rate of CO_2 release by natural activated sludge was 3.25–3.62 milligrams/1000 p.p.m. solids/hour.[5] The high rate of CO_2 release by the *Sphaerotilus* sludge may be attributed to the prior development of the organism on carbohydrate-rich media with the accumulation of carbohydrate reserve material within the cell. In order to ascertain how much CO_2 released by the mixture during the purification period, was derived from the sewage solids, the following calculations were made:

(1) Period in hours representing purification period	4
(2) CO_2 produced during purification period, mgm. C.	36.1
(3) Period of aeration after purification, hours	20
(4) CO_2 produced during period after purification, mgm. C.	91.6
(5) CO_2 produced per hour during period after purification, mgm. C.	4.58
(6) CO_2 contributed by sludge itself during purification period, mgm. C.	18.32
(7) CO_2 produced from sewage, mgm. C. (difference between 2 and 6)	17.8
(8) Organic carbon removed from sewage during purification period, mgm. C.	30.1
(9) Percentage CO_2 released from mixture during purification period derived from sewage solids	59

Approximately 60 per cent of the carbon dioxide released during the first four hours of aeration was derived from organic carbon in the settled liquor. During this four-hour aeration period, organic sludge carbon increased 12.4 p.p.m., while organic sludge nitrogen increased 5.5 p.p.m. After 24 hours of aeration however, the organic sludge carbon dropped 87.3 p.p.m. and organic sludge nitrogen 17.2 p.p.m. while the carbon dioxide released during this period was 91.6 mgr. per liter.

The rapid adsorption of suspended organic carbon which was observed by both natural activated sludge and zoogleal sludge was not evident with the *Sphaerotilus* sludge. The role played by the gelatinous masses characteristic of both *Zoogl*ea *ramigera* sludge and natu-

ral activated sludge may be of considerable importance. During the first four hours of aeration removal of suspended organic carbon from the settled liquor was 12.0 p.p.m. Removal of soluble organic carbon was 18.8 p.p.m. At the same time 17.8 p.p.m. CO_2 was produced during the first four hours of aeration, from the sewage. Since the carbon dioxide released from the sewage would be derived from organic carbon in solution rather than suspension, it would appear that the increase of organic carbon in the sludge was due principally to uptake of a small amount of suspended organic carbon present in the settled liquor. A decrease of 18.8 p.p.m. soluble organic carbon during the 4 hours aeration was paralleled by a calculated release of 17.8 p.p.m. CO_2 derived from soluble organic sewage solids. A decrease of 12.0 p.p.m. of suspended organic carbon in the settled liquor during the same period was paralleled by an increase of 12.4 p.p.m. of organic carbon in the sludge. From these figures it would appear that microbial proliferation of *Sphaerotilus* sludge during the purification period was limited. This is in accord with the earlier observation that development of *Sphaerotilus* sludge in sterile sewage devoid of carbohydrate enrichment failed to occur.

Summary and Conclusions

The sewage fungus, *Sphaerotilus,* was isolated from bulky activated sludge and a sludge of this organism developed. A study of the behavior of the *Sphaerotilus* sludge and the carbon and nitrogen transformations brought about by this organism enabled the following conclusions to be reached:

1. *Sphaerotilus* sludge did not grow well in sterile sewage devoid of carbohydrates. The building up of this sludge necessitated a prior development in carbohydrate rich media and was followed by transference of the cellular material to sterile sewage.

2. The *Sphaerotilus* sludge in concentration of 757 p.p.m. removed a maximum of 46 per cent turbidity and 56 per cent B.O.D. from sterile sewage in four hours aeration.

3. Rapid adsorption of suspended organic carbon by the sludge did not occur, although a limited slow removal of suspended organic carbon was observed. A majority of carbon removed by the *Sphaerotilus* sludge from the sewage was dissolved organic. The limited uptake of suspended organic carbon by the sludge was probably due to the absence of the gelatinous masses and great adsorbing surface which is characteristic of both *Zooglea ramigera* and natural activated sludges.

4. The fungus sludge appeared white and fluffy with a volume approximately three times that of an equivalent amount of zoogleal sludge. The sludge masses produced by *Sphaerotilus* were composed of threads of the organisms, now gelatinous and contained none of the zoogleal formations characteristic of pure culture zoogleal and natural activated sludges.

5. Carbon dioxide production was approximately double that of natural activated sludge and was attributed to the prior development

of the *Sphaerotilus* sludge on carbohydrate-rich media with the accumulation of carbohydrate reserve material within the *Sphaerotilus* cell. Approximately 60 per cent of the carbon dioxide released from the sludge-sewage mixture during the purification period was derived from the organic carbon in the settled liquor.

6. During the purification period of the sewage, the increase of *Sphaerotilus* sludge was due principally to the mechanical uptake of some of the suspended matter in the settled liquor, and secondarily, to the uptake of soluble organic matter.

7. Certain types of bulking of natural activated sludge appear to be the result of overgrowth of the sludge by filamentous organisms, notably *Sphaerotilus*. The sludges produced have high sludge indices and exert a moderate purifying action on sewage.

Bibliography

1. H. Heukelekian and M. L. Littman. Carbon and Nitrogen Transformations in the Purification of Sewage by the Activated Sludge Process. II. Morphological and Biochemical Studies of Zoogleal Organisms. This Journal, **11**, 752–763 (1939).
2. J. Smit. Bulking of Activated Sludge. *Ibid.*, **6**, 1041–1053 (1934).
3. R. S. Smith and W. C. Purdy. Studies of Sewage Purification. IV. The Use of Chlorine for the Correction of Sludge Bulking in the Activated Sludge Process. *Public Health Reports*, **51**, 617–623 (1936).
4. H. Heukelekian and M. L. Littman. Carbon and Nitrogen Transformations in the Purification of Sewage by the Activated Sludge Process. I. With Mixtures of Sewage and Activated Sludge. This Journal, **11**, 226–250 (1939).

STUDIES ON ACTIVATED SLUDGE BULKING

II. BULKING INDUCED BY DOMESTIC SEWAGE*

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"You have something which is called activated sludge; give it sufficient oxygen and it considers sewage a delicacy of the highest order and thrives on it."
—Dr. W. Watson.[7]

Factors which influence the bulking of activated sludge by carbohydrates were discussed in the previous paper of this series.[4] It is comparatively easy to induce this type of bulking under laboratory conditions. However, there are many instances of bulking in activated sludge plants where appreciable amounts of available carbohydrates, such as sugars and starches, cannot be detected in the sewage. No instances of bulking have been reported with carbohydrate-free sewage under laboratory conditions, including our experiments during the past ten years with activated sludge and from similar experiments at the Lawrence Experiment Station which have been conducted continuously since 1912.[1] If non-carbohydrate bulking could be reproduced under laboratory conditions the responsible factors could be studied under controlled conditions and a clearer understanding of the causes obtained.

It was pointed out previously [4] that the quantity and type of carbohydrate, the amount of nitrogenous material, the quantity and condition of the sludge all played an important role in the bulking of sludge. The proper combination of these factors induced an undue development of *Sphaerotilus*. Growth of this organism could occur under aerobic and anaerobic conditions and yet the carbohydrates caused *Sphaerotilus* to develop with an ample oxygen supply. The amount of air used under laboratory conditions to keep activated sludge in suspension is four to five times as high as the air supplied per unit volume of sludge mixture under plant conditions. It seemed possible to induce bulking with sewage if the air supplied could be reduced to volumes comparable with plant practice and still maintain the sludge in suspension. Since *Sphaerotilus* can grow under anaerobic conditions, the reduced amount of air might produce a sufficiently limited oxygen supply to induce the growth of *Sphaerotilus* and hence cause bulking of activated sludge with sewage.

This paper deals with experiments conducted under laboratory conditions in which the air supply to activated sludge mixtures was reduced to values comparable to various plant practices without permitting deposition of sludge. The flow of air was carefully regulated and measured. Under these conditions the importance of the rate of flow of air, sludge concentration and condition, sewage load and effect of nitrates on the bulking of activated sludge was determined.

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Methods

Nitrogen gas was used to dilute the air to the desired percentage of oxygen and still maintain sufficient volume of gases to keep the sludge in suspension. The diluted air thus obtained was used for the aeration of the activated sludge mixtures at a definite and constant rate. The apparatus used is shown in Fig. 1 and Plate 1. It consists of a 30 gal.

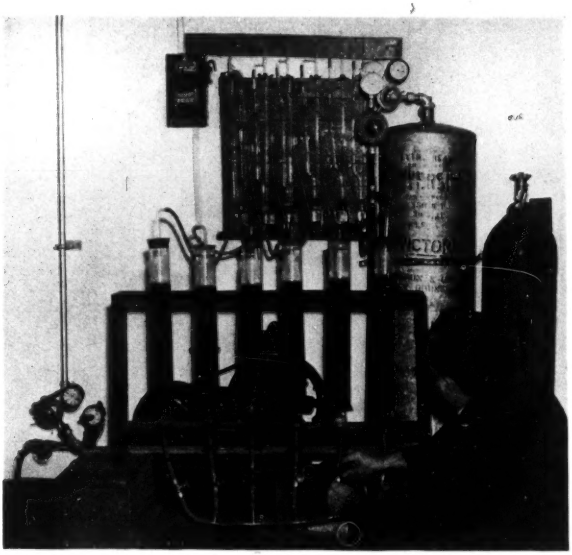

Plate 1.—Apparatus used for experimental work on aeration of activated sludge.

water tank fitted with two valves, one connected with an air compressor, and the other connected with a cylinder filled with compressed nitrogen. By means of the pressure gauge on the tank, the desired mixtures of air and nitrogen were made. An initial total pressure of 100 to 120 lb. of the gas mixture was found sufficient to last for an aeration period of 10 to 12 hours, depending on the number of aeration tubes used and the rate of flow of gases. The flow of the gas mixture to the aeration tubes was regulated by a reducing valve, followed by a line rectifier (Harris Calorific model 40A), and distributed to the individual tubes with needle valves. With the first reducing valve set to produce 15 lb. gas pressure and the line rectifier set for 5 lb., reductions in the tank gas pressure from 100 down to 5 lb. failed to produce a fluctuation in the flow of the gas mixture. Without the line rectifier, however, a small decrease in the tank pressure was reflected in the flow of the gas through the aerators. The exhaust gas from the aeration tubes was led through

a glass orifice which produced a differential pressure proportional to the flow of gas. By measuring the rise in the liquid level for known rates of flow of gas, each capillary was calibrated. The flow of gas mixture through each aeration tube was regulated to the desired value with a needle valve. After the flow of the gas mixture was adjusted the liquid level remained constant and the flow of the gas did not vary more than ± 5 per cent.

The operating schedule was on a fill-and-draw basis, dosings being made three times a day. The air was turned off at 8:30 A.M., and after

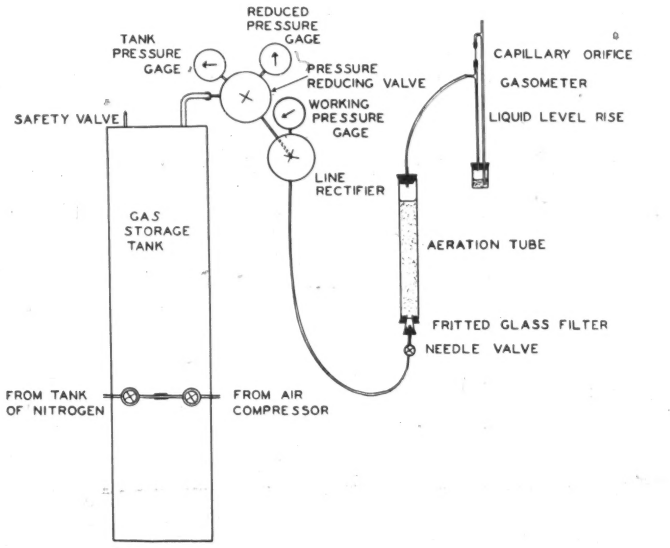

FIG. 1.—Diagramatic presentation of the apparatus used for experimental work on aeration of activated sludge.

a half-hour sedimentation period the supernatant was withdrawn and a dose of sewage was added and the mixture aerated until 3 to 4 P.M. After settling for one-half hour, the sample was dosed and aerated until 9 to 10 P.M. The procedure was repeated again at 9 to 10 P.M. Thus the aeration period was 6 hours for each of the two doses during the day and 10 hours for the night period.

Sewage used in these experiments was fresh settled sewage from a domestic source, with a B.O.D. of 250 to 350 p.p.m. The activated sludges were obtained from various plants in the vicinity. Not more than 3 to 4 hours elapsed between the time they were sampled and the experiments were set up.

The sludge index was calculated according to Mohlman [8] by obtaining the volume in per cent of settled sludge after one-half hour sedimentation, and dividing it by the suspended solids concentration of the original mixture, also in per cent.

Results

Before presenting the results of the effect of reduced oxygen concentration in the air supply on the bulking of activated sludge, the effect on purification is given (Table I). The effect of air, nitrogen and vari-

Table I.—*Effect of Oxygen Concentration of the Air on the Rate of Purification of Sewage by Activated Sludge* [a]

Per Cent Oxygen in Gas Used	NH_3 – N P.p.m. Initial 33 P.p.m. Hours Aeration				NO_3 – N P.p.m. Initial 0.5 P.p.m. Hours Aeration				Turbidity P.p.m.[b] Initial 100 P.p.m. Hours Aeration				B.O.D. P.p.m.[b] Initial 62 P.p.m. Hours Aeration			
	1¼	2¾	4	5	1¼	2¾	4	5	1¼	2¾	4	5	1¼	2¾	4	5
20.0	27	18	16	13	5.6	10.0	14.0	16.0	65	35	31	16	28	18	15	12
10.0	30	20	17	14	4.5	8.0	10.0	11.0	67	37	35	31	30	26	11	10
5.0	32	26	22	19	2.0	2.0	2.0	5.0	77	47	47	55	34	28	21	19
2.5	34	30	30	–	0.4	0.4	2.0	—	90	60	65	—	45	35	27	—
0.0	36	30	36	33	0.6	0.0	0.0	0.0	122	105	110	110	87	90	95	110

[a] The aeration was adjusted visually to a rate to prevent sedimentation. This experiment was run before an accurate method of regulating and measuring the flow of air was developed.

[b] These tests were made on paper filtered liquors.

ous mixtures of the two gases on the rate of purification was determined as measured by ammonia nitrogen, nitrate nitrogen, turbidity and B.O.D. of the liquor. The results showed that purification was most rapid with air and absent with nitrogen. A low B.O.D. value was obtained with air within 3 hours. (The initial low B.O.D. value does not represent the original strength of the sewage since the sewage was mixed with sludge, settled and the supernatant liquor filtered through paper.) Within a similar period of aeration 10 p.p.m. of nitrate nitrogen was produced by the use of air. As the percentage of oxygen was reduced, the rate of purification and oxidation was retarded. With 5 per cent oxygen in the gas mixture, it required five hours to reach a similar B.O.D. value as with air in 2¾ hours, while nitrate nitrogen was lower with 5 per cent oxygen in 5 hours than with air in 2¾ hours. It would seem, therefore, that to reach an end-point of purification under laboratory conditions similar to plant operation, either a 2 to 3-hour dosing cycle should be practiced or the oxygen concentration in the air supply should be reduced. The actual percentage of oxygen required to give rates of purification equivalent to plant practice will naturally vary with sludge concentration and condition, and with sewage load, etc. It is only necessary to establish here the reason for the failure of the laboratory experiments to reproduce plant conditions in regard to non-carbohydrate bulking. It was shown earlier [2] that

nitrogen gas bubbled through activated sludge mixtures fails to purify, neither does passing nitrogen gas through activated sludge mixtures cause the sludge to bulk. That a certain amount of purification is essential before bulking will take place will be shown in conjunction with some of the other experiments presented below.

The effect of passing different amounts of 5 per cent oxygen gas mixture through relatively high and low sludge concentrations in the mixtures of activated sludge and sewage is given in Table II and Fig. 2.

TABLE II.—*Effect of Different Rates of Application of 5 Per Cent Oxygen Gas Mixture on the Rate of Bulking at Two Different Sludge Concentrations*

	Air Supplied		Suspended Solids		Settling		Sludge Index	
	C.c./min./liter of Act. Sl. Mixture[a]	Cu. Ft. Air/gallon[b]	Initial	After 3 Doses	Initial	After 3 Doses	Initial	After 3 Doses
			P.p.m.	P.p.m.	Per Cent	Per Cent		
1	60	0.72	2245	1995	25	61	110	306
2	90	1.08	2245	1930	25	50	110	259
3	120	1.44	2245	2020	25	39	110	193
4	60	0.72	975	1035	8	23	82	222
5	90	1.08	975	1040	8	18	82	173
6	120	1.44	975	970	8	13	82	134

[a] On the basis of flow of mixture of gas containing 5 per cent oxygen.
[b] On the basis of air containing 20 per cent oxygen and 6 hour aeration period.

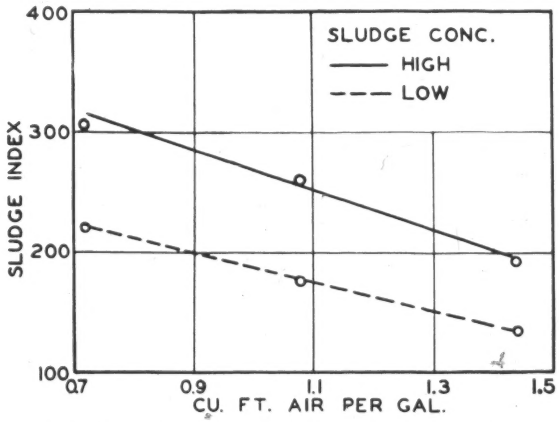

FIG. 2.—The effect of the relation between sludge concentration and quantity of air used upon the sludge index.

Sludge indices of all the mixtures increased after three doses of sewage. The greatest increase was with the lowest flow of gas. Even with a flow of 1.44 cu. ft. of air per gallon of the mixture per 6 hours, the initial sludge index could not be maintained with the sewage load added

under these experimental conditions. Fig. 2 shows a straight line relationship between sludge index and air flow for the three flows used in this experiment.

Sludge concentration was also a factor in the rate of bulking, and was studied in greater detail. Four activated sludge sewage mixtures, varying in initial suspended solids concentration from 400 to 2430 p.p.m. were dosed three times with sewage and aerated with a 5 per cent oxygen mixture of gas. They received equal volumes of the same sewage. The suspended solids of the mixtures, the sludge volumes and the sludge index values initially and after the third dose are given in Table III.

TABLE III.—*Effect of Sludge Concentration on the Rate of Bulking with 5 Per Cent Oxygen in the Gas Supplied for Aeration**

No.	Suspended Solids			Settling		Sludge Index	
	Initial	After 3 Doses	Increase	Initial	After 3 Doses	Initial	After 3 Doses
	P.p.m.	P.p.m.	P.p.m.	Per Cent	Per Cent		
1.	400	680	280	5.0	8.3	125	122
2.	790	1100	310	9.0	18.0	114	164
3.	1100	1440	340	15.0	32.0	136	222
4.	2430	2450	20	35.0	52.0	144	212

* At the rate of 80 c.c. of diluted air/min./liter of sludge mixture or 0.96 cu. ft. of air per gallon.

Since no attempt was made to maintain the suspended solids concentration to the initial values, the concentrations of the different mixtures increased, except the one with the highest initial value. In spite of the increases in sludge concentration the ranges for each sludge concentration do not overlap. With the exception of the highest sludge concentration sludge accretion was greater with higher amounts of sludge used initially. The sludge index in the lowest suspended solids concentration (400 p.p.m.) remained unchanged. Increases of sludge index were obtained with the higher sludge concentrations. The greatest increase in sludge index occurred with highest sludge accretion. Thus, when conditions were such that an appreciable sludge build-up did not take place, the rate of increase of sludge index was not as great. Yet, at the lowest sludge concentration with considerable increase in sludge build-up, there was no increase in sludge index.

In the following experiment a comparison was made of the effect of maintaining a constant sludge concentration (by wasting of sludge) and increasing sludge concentration (no wasting). The results obtained after a number of dosages had been applied are given in Table IV. Where the sludge was not wasted the concentration of sludge increased from 785 p.p.m. to 1165 p.p.m. and the sludge index increased from 216 to 370 with five doses. At this point this mixture was discarded. When the sludge was wasted the concentration of suspended solids increased somewhat with five doses of sewage, but at the end of the eleventh dose it was nearly at the initial level. The sludge index similarly

TABLE IV.—*Effect of Maintaining a Constant Sludge Concentration on the Bulking of Activated Sludge* *

	Suspended Solids			Settling			Sludge Index		
	Initial	5th. Dose	11th. Dose	Initial	5th. Dose	11th. Dose	Initial	5th. Dose	11th. Dose
	P.p.m.			Per Cent	Per Cent	Per Cent			
Sludge not wasted..	785	1165	—	17	43	—	216	370	—
Sludge wasted.....	785	860	770	17	23	16.5	216	270	215

* Aerated with 5 per cent oxygen mixture at the rate of 80 c.c. per minute per liter of activated sludge mixture or 0.96 cu. ft. of air per gallon.

increased at the fifth dose but was back at the initial value at the eleventh dose. Thus at a sludge concentration of about 800 p.p.m. bulking could be prevented with an air application of 0.96 cu. ft. per gallon, but if the solids were allowed to increase to 1100 p.p.m. or more, sludge bulked readily with the same amount of air. The increase in sludge index with 790 p.p.m. suspended solids as observed in Table III can be attributed to the increase of sludge concentration to 1100 p.p.m. It is doubtful whether bulking of the mixture with an initial suspended solids concentration of 1100 p.p.m. could have been prevented even if the solids were not allowed to increase.

An attempt was made to determine the effect of prolonged reaeration of sludge on the bulking of activated sludge with sewage. The condition of the sludge was changed experimentally by aerating the sludge with sewage for various periods with normal air (20 per cent oxygen). It was thought that by this procedure the sludge could be oxidized to such an extent that when dosed with sewage and aerated with an oxygen concentration of 5 per cent, differences in the response of the sludge bulking might be obtained. Accordingly, a portion of a sludge as obtained from a plant was mixed with sewage and aerated with a gas mixture containing 5 per cent oxygen at a rate of 80 c.c. per minute per liter of mixture. This mixture was aerated for 2 days with 6 doses of sewage. A portion of the original sludge was simultaneously aerated with sewage with 20 per cent oxygen for 24 hours. At the end of this period a sample was taken, settled and the sludge mixed with sewage and aerated with 5 per cent oxygen gas mixture at a rate of 80 c.c. per minute per liter of mixture. This sludge also received six doses of sewage. After 5 days of aeration with a dose of sewage per day with normal air, the balance of the sludge was treated in the same way as the sample with 24 hours aeration. It was dosed 6 times with sewage and aerated with a 5 per cent oxygen gas mixture at the rate of 80 c.c. per minute per liter of mixture. The results are given in Table V. Nitrate determinations were made on the sludge liquor as obtained and again after aeration with normal air for one and five day periods prior to mixing it with sewage. The suspended solids concentration of the initial mixtures made with sludge as obtained and after aeration for 24

TABLE V.—*Effect of Sludge Conditions on the Rate of Bulking of Activated Sludge*

	Sludge as Received		After Aeration with Sewage for 24 hrs. with 20 Per Cent Oxygen		After Aeration with Sewage for 5 days with 20 Per Cent Oxygen	
	Initial	After 6 Doses*	Initial	After 6 Doses*	Initial	After 6 Doses*
Suspended solids, P.p.m.	1100	1360	1155	1515	1500	1975
Settling, Per cent	14	48	11.0	45	13	19.5
Sludge index	127	350	95	300	87	100
$NO_3 - N$, P.p.m.	0.8	—	40	—	25	—

* Aeration with 5 per cent oxygen gas mixture at the rate of 80 cc. per minute per liter of sludge mixture.

hours, were almost alike while the mixture made up after five days aeration had a somewhat higher initial suspended solids concentration. After 6 doses of sewage with reduced oxygen supply the sludge index of the original sludge increased from 127 to 350. Aeration of the sludge for a prior period of 24 hours decreased the initial sludge index to 95, but after 6 doses of sewage with reduced oxygen supply, the index increased to 300. However, after five days aeration with 20 per cent oxygen, the sludge index increased from 87 to only 100 when the mixture was aerated with reduced oxygen supply and dosed the same number of times with sewage. This slight increase occurred in spite of the fact that both initial and final suspended solids concentrations were higher than in the previous mixtures. Some change had been brought about in the sludge condition during this period of aeration with normal air which enabled the sludge to withstand conditions which otherwise would have induced bulking. That this was not entirely due to nitrification or nitrate content is evident from the rapid bulking of the sludge aerated for a period of 24 hours with normal air and having a considerable amount of nitrates. However, nitrates as such are a factor as is indicated from results obtained in the following experiment. Three identical portions of activated sludge were dosed with sewage and aerated with a 5 per cent oxygen gas mixture. Two of the mixtures received 10 and 20 p.p.m. of nitrate nitrogen, respectively, with each dose of sewage while the third mixture served as the control receiving the sewage doses without the nitrate. The results are given in Table VI. The sludge index of the control increased from 216 to 370 while the mixtures receiving nitrates showed decreases in the sludge indices below the initial values after 6 doses. Nitrate determinations made during the sixth dosing period showed the following amounts of nitrates at different times:

$NO_3 - N$ Added	Nitrate Nitrogen Found in P.P.M.				
	Initial	½ hr.	3½ hr.	4¾ hr.	6.0 hr.
10 p.p.m.	12.0	8.5	7.0	10.0	11.0
20 p.p.m.	20.0	20.0	20.0	20.0	22.0

TABLE VI.—*Effect of Addition of Nitrates on Bulking of Activated Sludge with Sewage* *

	Suspended Solids		Settling		Sludge Index	
	Initial	After 5 Doses	Initial	After 5 Doses	Initial	After 5 Doses
	P.p.m.	P.p.m.	Per cent	Per cent		
Control	785	1165	17	43	216	370
10 P.p.m. $NO_3 - N$	785	1225	17	24	216	196
20 P.p.m. $NO_3 - N$	785	1250	17	22	216	176

* Aeration with 5 per cent oxygen gas mixture at the rate of 80 c.c. per minute per liter of sludge mixture.

It appears that a certain amount of reduction of nitrates took place with the addition of 10 p.p.m. of nitrates but none with the 20 p.p.m. addition. Since the nitrate determination by the reduction method includes both nitrites and nitrates a reduction of nitrates to nitrites is not registered, although it may have occurred with the larger amounts of nitrates. In a subsequent paper the validity of this explanation will be considered.

The next factor to be considered is the effect of the strength of sewage and aeration period on the bulking of sludge (Table VII).

TABLE VII.— *Effect of Strength of Sewage and Aeration Period on the Bulking of Activated Sludge* *

Dosing	Suspended Solids		Settling		Sludge Index	
	Initial	After 6 Doses	Initial	After 6 Doses	Initial	After 6 Doses
	P.p.m.	P.p.m.	Per cent	Per cent		
Full strength sewage 3xday	1100	1360	14.0	48	127	350
1/3 strength sewage 3xday	1100	1065	14.0	12	127	113
Full strength sewage 1xday	1100	1170	14.0	17	127	145

* Aeration with 5 per cent oxygen gas mixture at the rate of 80 c.c. per minute per liter of sludge mixture.

Three mixtures of activated sludge were fed with (1) full strength sewage three times a day, (2) sewage diluted to one-third its original concentration with tap water and added three times a day in a volume equal to No. 1, (3) full strength sewage added once a day. The mixtures were aerated with a 5 per cent oxygen gas mixture at a rate of 80 c.c. per minute per liter of mixture. Six dosings were made in each case so that mixture No. 2 received only one-third the amount of sewage load as compared with mixtures 1 and 3, while mixture No. 3 received the same amount of sewage load in three times the period of time as mixture No. 1. The sludge index in the mixture dosed with full strength sewage three times a day increased from 127 to 350, while feeding sewage one-third the original strength did not cause any increase in the sludge index. Feeding full strength sewage once a day increased the sludge index from 127 to only 145.

The effect of temperature on the bulking of activated sludge is illustrated in Table VIII. The effect of two different rates of flow of 5 per

TABLE VIII.—*Effect of Temperature on the Bulking of Activated Sludge*

No. of Doses	Temperature	Rate of Flow*	Susp. Solids	Settling	Sludge Index	Turbidity†*
	°C.	C.c.	P.p.m.	Per cent		P.p.m.
0	—	—	890	10	112	—
6	10	80	1690	14	83	47
6	10	160	1605	14	87	60
6	20	80	1695	46	270	4
6	20	160	1650	25	150	8
6	30	80	1505	60	400	6
6	30	160	1420	20	140	8

* Aeration rate 80 and 160 c.c. per minute per liter of mixture of 5 per cent oxygen gas equivalent to .96 and 1.92 cu. ft. air per gallon.

† After sixth dose.

cent oxygen gas mixture at 10°, 20°, and 30° C. were compared. The results show that at the lower rate of aeration the most aggravated bulking took place at 30° C. and the next at 20° C. The higher rate of aeration was able to counteract the effect of higher temperatures in inducing bulking. At 10° C. there was no indication of bulking with either rate of aeration.

In Table IX are given the results of aerating two activated sludges at different temperatures with normal air (20 per cent oxygen) and 5 per cent oxygen gas mixture at equal rates of flow. When 5 per cent oxygen gas mixture was used for aeration the highest sludge index was obtained at 20° C. and not at 30° C. as was obtained in the previous ex-

TABLE IX.—*Effect of Temperature on the Bulking of Activated Sludge Aerated with Five and Twenty Per Cent Oxygen Gas Mixture*

Sludge	Temp.	5 Per Cent Oxygen[a]				20 Per Cent Oxygen[a]			
		Doses	Suspended Solids	Sludge Index	Turbidity[b]	Doses	Suspended Solids	Sludge Index	Turbidity[c]
	°C.		P.p.m.		P.p.m.		P.p.m.		P.p.m.
A	—	0	830	180	—	0	640	310	—
A	10	5	1225	163	20	3	1000	190	20
A	20	5	1040	394	17	3	845	213	13
A	30	5	920	315	150	3	785	320	16
B	—	0	700	300	—	0	865	230	—
B	10	5	1450	145	30	3	1075	204	27
B	20	5	1220	310	35	3	1090	266	25
B	30	5	610	145	190	3	960	312	65

[a] Aeration rate 80 c.c. per min. per liter of activated sludge mixture.

[b] After fifth dose.

[c] After third dose.

periment. However, there was little if any clarification and sludge increase at 30° C. as indicated by the turbidity and suspended solids values. When air containing 20 per cent oxygen was used the highest sludge index with both sludges was obtained at 30° C. Clarification at this temperature was fair.

Experiments presented so far were made with activated sludge sewage mixtures. In order to determine the effect of reaeration of sludge on the sludge index with amounts of air comparable to plant practice, two sludges at two different suspended solids concentrations were aerated continuously for four days with 2.5 per cent oxygen gas mixture and normal air. The results obtained are given in Table X. The

TABLE X.—*Effect of Reaeration of Sludge with Reduced Oxygen Concentration and Normal Air on the Sludge Index*

Sludge	2.5 Per Cent Oxygen						20 Per Cent Oxygen					
	Susp. Solids		Settling		Sludge Index		Susp. Solids		Settling		Sludge Index	
	Initial	Final*	Initial	Final*	Initial	Final*	Initial	Final*	Initial	Final*	Initial	Final*
	P.p.m.	P.p.m.	Per cent	Per cent			P.p.m.	P.p.m.	Per cent	Per cent		
A	2670	1855	97	99	363	535	2670	1630	97	88	363	540
A	635	385	27	19	430	500	635	250	27	7	430	280
B	5000	4385	40	60	80	137	5000	4030	40	29	80	72
B	1250	1025	10	9	80	88	1250	1010	10	9	80	88

* After 4 days.

sludge index increased when the sludges were aerated with a 2.5 per cent oxygen gas mixture. The greater increase in the sludge index took place with the higher suspended solids concentration. Even with 20 per cent oxygen in the air supply, the sludge index of sludge A at the high concentration increased. At low suspended solids concentration the sludge index of sludge A decreased. Sludge B did not show a material change in the sludge index. The decrease in suspended solids of the two sludges are given in Table Xa. The greatest suspended solids reduction took place with the normal air at the low suspended solids concentration. Sludge A lost more suspended solids under similar conditions than sludge B.

TABLE Xa.—*Decrease in Suspended Solids Concentration of Sludges Aerated with 2.5 Per Cent and 20 Per Cent Oxygen in the Air Supply*

Sludge	2.5 Per Cent		20 Per Cent	
	P.p.m.	Per cent	P.p.m.	Per cent
A	815	32	1040	39
A	250	39	385	61
B	615	12	970	19
B	225	18	240	19

Discussion

Evidence has been produced that activated sludge can be made to bulk under laboratory conditions when fed with sewage. The oxygen in the gas mixture was reduced to one-quarter of its normal concentration in air. On the basis of the amount of gases per unit volume of the mixture of sludge, this represents an oxygen supply equivalent to about 1.0 cu. ft. of air per gallon of sewage. Under certain conditions this amount of oxygen results in bulking of sludge in the laboratory. Bulking of sludge has been shown to take place under certain conditions when similar amounts of oxygen are supplied in the plant. It seemed probable that oxygen deficiency was one of the primary causes of non-carbohydrate bulking of activated sludge in both laboratory experiments as well as in plant practice.

It is not valid to assume that with so much air supplied to activated sludge, oxygen deficiency cannot occur. It is common knowledge that most of the oxygen in the air escapes unused except for agitation, and when the amount of air is increased in an attempt to check bulking, a still greater quantity is wasted. The solution rate of oxygen is extremely low and when the demand is high a deficiency of oxygen can readily develop in spite of the high air input. The solution rate of oxygen depends upon the partial pressure of oxygen in addition to the quantity of air. This brings up an obvious criticism of our method of experimentation, because in using diluted air, the lower partial pressure of the oxygen lowers the saturation value. The error from this source is limited because with a higher partial pressure at the plant, saturation values are not obtained in the aeration tanks. In a subsequent paper the results on the dissolved oxygen content of activated sludge liquors will be presented. Another variable that may make direct comparisons difficult between laboratory studies and plant practice is the prevalence of short circuiting in aeration chambers which is absent in the laboratory method of aeration.[5] This might tend to make the oxygen deficiency in a plant more positive and the sludge more prone to bulking for a given flow of air and oxygen demand. On the other hand, the batch method of aeration in contrast with the continuous method, may make the sludge more susceptible to bulking under laboratory conditions by causing an initial overloading. An experiment on this phase might reveal whether the feeding of sewage as is now generally practiced at plants can be improved upon by introducing the sewage at different points in the aeration tank similar to the provisions made at Tallman's Island and Columbus plants. In the final analysis it is probable that the balance of the factors in the method of operation at plants and under laboratory conditions tends to be even and that at least general tendencies obtained from laboratory experiments might be applied to an explanation and control of bulking in plants.

What are the specific conditions and factors that set up an oxygen deficiency in the laboratory experiments, and how can they be applied to plant conditions?

It has been established that the quantity of air as practiced under laboratory conditions is one of the determining factors in the rate of bulking. It would seem, therefore, that one of the ways in which bulking may be checked is by increasing the air supply. However, when sludge is already bulky, it is doubtful whether sufficient air can be supplied in reaeration tanks to improve its settling within a reasonable length of time.

With a given air flow and sewage load, sludge concentration has been shown to be an important factor in determining the rate of bulking. The higher the sludge concentration within limits, the more rapid will be the rate of bulking. It is reasonable to ask why beyond certain limits of sludge concentration bulking does not become more rapid. The answer should be sought in the fact that as the sludge concentration increases beyond certain limits the quantity of sewage per unit amount of sludge decreases. Each organism within the sludge will obtain less food and therefore more of the food will be used for maintenance and less for multiplication. This will prevent an excessively rapid increase in the numbers of sludge organisms in general and of *Sphaerotilus* in particular. Substantiation of this view is obtained from the fact that at a higher sludge concentration the bulid-up of sludge becomes smaller. In other words, bulking is induced by an excessive development of sludge or certain organisms comprising the sludge, due to the improper balance of food in relation to the sludge. This does not mean that with higher sludge concentrations a greater sewage load should be added in order to overcome bulking, because by doing this the total oxygen demand is increased, which in turn will tend to cause bulking. The real solution seems to be a proper balance between food, sludge and air supply. The importance of food supply is amply illustrated by the bulking rates of diluted and strong sewage applications. With dilute sewage the air supply can be reduced with impunity while with strong sewages it may be well nigh impossible to check bulking with the aeration facilities available. This also explains why dry weather flow has been observed to cause difficulty with sludge bulking. However, since the total load remains the same under dry weather conditions it is reasonable to ask whether it is the concentration of sewage *per se* that is the determining factor. The answer to this can be given from the results of the experiments presented in Table VII. Although full strength sewage fed to the sludge once a day gave a lower index than the same sewage fed three times a day, yet it had a higher index than the mixtures fed with one-third the strength of sewage three times a day. The total amount of sewage fed being the same, the more dilute the sewage the less the bulking. With strong sewage during dry weather flow the practice of returning effluent or pumping river water seems to be based on a sound principle, to check bulking. Whether it is the dissolved oxygen introduced by the diluting water or the reduction in the concentration of polluting material that is beneficial cannot be definitely answered at present.

The condition of the sludge plays an important role in bulking. It is difficult to define "sludge condition" except in general terms, such as stage of oxidation or a nitrifying and non-nitrifying power. Thus a sludge with a fairly low initial sludge index and low nitrate content is made more and more difficult to bulk as a result of aeration with an ample oxygen supply (Table V). These results can be interpreted on the basis of: (1) the lower oxygen demand requirement of the sludge as a result of a prolonged period of reaeration, or (2) to the shift in the flora as a result of reaeration whereby *Sphaerotilus* is greatly reduced in numbers. However, such long periods of reaeration in order to make the sludge unresponsive to bulking are not practical.

The addition of nitrates to the sewage prevented the bulking of the sludge. The results cannot be fully explained with the data on hand on the basis of the reduction of nitrates and the liberation of oxygen. However, there is no *a priori* reason why nitrates cannot be reduced under conditions of oxygen deficiency and the oxygen liberated used for the oxidation process. That an actual reduction of added nitrates to nitrites and gaseous nitrogen takes place with certain non-nitrifying sludges during the first two hours of aeration, has been reported in the 1939 Report of the Water Pollution Research Board.[12] Naturally the addition of nitrates for the prevention or checking of bulking is bound to be expensive but when a natural source of nitrates is available such as in trickling filters the returning of such an effluent to an aeration tank as has been done by Kershaw and Finch [6] will have the triple effect of reducing the concentration of sewage and adding both dissolved oxygen and combined oxygen (nitrates).

The effect of nitrates in preventing sludge bulking should not be confused with sludge rising which according to O'Shaugnessy and Hewitt [9] is due to the entrainment of nitrogen gas derived from the reduction of nitrates. The value of the addition of nitrates to prevent bulking will be in the aeration tanks whereas blanket rising takes place in settling tanks.

The lower the temperature the less the tendency will be toward bulking. In other words the bulking troubles encountered in the summer time might partly be due to the higher temperatures in addition to the stronger sewage. However, the relationship is complicated by certain other factors. With certain sludges a worse condition of bulking is encountered at 20° C. than at 30° C. Such sludges fail to clarify and increase in concentration at 30° C. (Table IX) but when these sludges are aerated with straight air the highest sludge index occurs again at 30° C. and clarification is good. The underlying explanation for this phenomenon is that certain sludges with a high oxygen requirement fail to clarify sewage at 30° C. with limited oxygen supply, because of the high oxygen demand created at this temperature. With no clarification the sludge fails to obtain the necessary food and no bulking occurs. When the oxygen supply is increased the clarification, or the assimilation of pollutional material from sewage by the sludge, proceeds unhampered even at 30° C., and sludge development takes place causing

bulking. That no bulking occurred at 10° C. with the sewage load and oxygen supply used can be explained on the basis of the slow biological assimilation of pollutional materials from sewage or the increased oxygen solution. The fact that sewage is clarified at this low temperature does not contradict this view, since biological assimilation is considerably retarded irrespective of clarification. A link is thus established between bulking and purification. When there is very little purification under conditions described above, or under still more exaggerated condition when a sludge mixture is agitated with nitrogen, there is no possibility of bulking. With overaeration of sludge as is the case when small volumes of sludge mixture are aerated with straight air under laboratory conditions with two or three daily dosages of sewage there is again very little chance of bulking. It is only when there is some oxygen for purification but not sufficient for complete stabilization that bulking takes place.

It has been demonstrated that even in the absence of sewage, aeration of sludge under certain conditions may result in poorer settling of sludge. This occurs with a deficiency of oxygen and particularly when high concentrations of sludge are reaerated. This explains why reaeration of sludge has not universally proven of definite value in checking bulking. When the oxygen demand of a sludge in a reaeration tank is high due either to its condition or concentration or both, and when the oxygenation capacity is low, a rise in the sludge index is not surprising.

It has been shown that the rate of purification is much faster when normal air is used for aeration of activated sludge mixtures under laboratory conditions than under plant conditions. The end-point reached within 2–3 hours in the laboratory is similar to that obtained in 6–8 hours under plant conditions. The reasons for this have been explained on the basis of the higher amount of air used to keep small volumes of sludge in suspension, absence of short circuiting, etc. There is one obvious deduction to be made from this observation, that conclusions drawn from laboratory experiments using straight air cannot be applied directly to plant practice. For the same reason that oxidation and purification accomplished under such laboratory conditions with normal air are so rapid as to make it difficult to produce bulking of sludge with sewage, similarly, oxygen demand tests made with small volumes of sludge and sludge mixtures aerated with normal air cannot represent the actual demand of the sludge in a plant with relatively inefficient aeration methods. In order to conduct such experiments under laboratory conditions to even approximate the values under plant conditions, reduced oxygen concentrations should be used for aeration. The actual oxygen concentration to be used for aeration will depend on the concentration required to produce equivalent rates of purification. In other words, if a plant is producing an effluent with 5 p.p.m. B.O.D. and 6 p.p.m. nitrates with a given strength of sewage and sludge concentration, such an oxygen concentration and rate of flow of gas should be selected for laboratory tests that will just reach these values only after

6 hours aeration and not after 3 to 4 hours. If tests are conducted under these conditions then some of the anomalies observed between plant practice and laboratory tests may be ironed out.

How do the various factors that effect bulking of sludge by means of carbohydrates and sewage compare with each other? The factors influencing carbohydrate bulking as presented in the previous paper of this series are summarized and compared in the tabulation below with the factors as obtained in the present paper with sewage bulking.

	Factors	Carbohydrate Bulking	Sewage Bulking
1.	Oxygen supply to produce bulking	Up to 20 per cent	Around 5 per cent
2.	Effect of food concentration	Higher food concentration gives more bulking	Higher food concentration gives more bulking
3.	Effect of sludge concentration	Lower sludge concentration gives more bulking	Higher sludge concentration gives more bulking
4.	Sludge condition	More highly oxidized sludges bulk less rapidly	More highly oxidized sludges bulk less rapidly
5.	C – N Ratio	Too wide a ratio induces bulking	This factor is being investigated
6.	Effect of temperature	?	The higher the temperature the more readily the sludge bulks
7.	Effect of nitrates	Retard but do not prevent	Prevent

It should be stated at the outset that there is no difficulty in producing bulking with carbohydrates when normal air is used for aeration, whereas bulking cannot be produced with sewage in the laboratory unless the oxygen supplied in the air is cut down. The concentration of sugar that produces an increase in sludge index with normal air is about 125 p.p.m. or more. This would have a 5-day B.O.D. of about 60 p.p.m. A sewage with a similar B.O.D. cannot be made to bulk even when it is aerated with one cu. ft. of air per gallon. It is our opinion therefore that carbohydrates are specific stimulants in inducing bulking when they are present. In other words their concentration need not be high enough to create an oxygen deficiency but their presence in appreciable quantities will stimulate the growth of *Sphaerotilus* over Zooglea. This is in accord with the views presented in the previous paper.[4] Undoubtedly when the concentration of carbohydrates is high enough, in addition to this specific response of *Sphaerotilus* to carbohydrates, an additive factor of oxygen deficiency may be created which will cause the further preponderance of *Sphaerotilus* over Zooglea. It has been stated in the previous paper that Zooglea is strictly an aerobic organism while *Sphaerotilus* functions both under aerobic and anaerobic conditions. *Sphaerotilus* can utilize the sugar preferentially to the Zooglea under aerobic conditions, while under anaerobic conditions the Zooglea cannot utilize the sugar. The evidence for these generalizations is fragmentary and a more thorough study of the physiology of the *Sphaerotilus* and Zooglea in regard to carbohydrate metabolism

and response to anaerobic conditions would greatly aid in establishing these views. However, this explanation fits all the facts so far observed and there have been no discordant results.

The most important factor in the more prevalent non-carbohydrate bulking is the oxygen deficiency, although under certain conditions a high concentration of sewage *per se* may play a role.

There is a real difference in the behavior of the two types of bulking in regard to sludge concentration. With sugar, lower sludge concentrations produced a greater rate of bulking while the opposite results are obtained with sewage. Table XIII in the previous paper [4] shows greater increases in sludge index with higher sugar-sludge ratios. The same tendency was evident when sugar-sludge ratios were changed by keeping the sugar addition constant and varying the sludge concentration or vice versa. In other words this type of bulking is due to an improper balance of food to sludge. Similar conclusions were drawn regarding sewage bulking. The difference is therefore only apparent and is due to the fact that the sewage-sludge ratio cannot be changed without changing both factors, *e.g.* when different concentrations of sludge are fed with equal volumes of sewage, the mixture with the highest concentration is receiving the least amount of sewage per unit amount of sludge, while sugar is fed in a concentrated form to any amount of sludge.

The behavior of sludge bulking in relation to sludge condition is the same whether the food is added in the form of sugar or sewage *e.g.*—the sludge index increases more slowly, the more the sludge is oxidized whether it is fed with sugar or sewage.

It was previously reported that without the addition of some nitrogenous compound, sugar did not cause any bulking. As the amount of nitrogenous material added was increased up to a certain value, bulking with sugar became more aggravated. Beyond this value bulking was retarded. This was explained on the basis of the inability of the sludge organisms to utilize the sugar without a source of nitrogen. As the utilization of sugar was made possible by the addition of nitrogenous material, bulking became more aggravated. It was pointed out that *Sphaerotilus* could utilize the sugar more readily with an inadequate supply of nitrogenous material than Zooglea and the retardation of bulking with ample quantities of nitrogenous materials was ascribed to the competition of Zooglea organisms with the *Sphaerotilus* for the sugar added. The values expressed on the basis of carbon-nitrogen ratio were 40:1 to 10:1 as ratios promoting bulking, and 8:1 or below as ratios retarding bulking. Most domestic sewages have a narrow C–N ratio and it does not seem probable that this will be a factor in bulking with sewage. It has been shown that this ratio may vary considerably [11] and the effect of varying the carbon-nitrogen ratio of sewage on the bulking of sludge will be presented in the subsequent paper.

The temperature response of sugar bulking is not known at present.

The addition of nitrates retards bulking caused by the addition of

sugar to sludge but it definitely prevents it when it is added in conjunction with sewage. It is believed that the differences in the factors responsible for bulking of sludge with sugar and with sewage explain the differences in the response to the addition of nitrates. If the assertions are true that bulking caused by sugar is primarily due to a food response and not an oxygen deficiency, the addition of nitrates in conjunction with sugar will play only a minor role by increasing the oxygen supply (denitrification). On the other hand, when oxygen deficiency conditions prevail in conjunction with the bulking of sludge with sewage, the addition of a combined form of oxygen as nitrates which can readily be denitrified, must play a definite role in preventing bulking.

The above discussion has emphasized the importance of the proper relation between deoxygenation and oxygenation capacity for the prevention of bulking. The latter term was first introduced by Kessener and Ribbious.[7] The deoxygenation factor is dependent upon (*a*) the sewage strength, (*b*) sludge concentration, (*c*) sludge activity (*i.e.* the extent of the increase in the oxygen demand of the sludge by aerating it with sewage), and (*d*) temperature. Practically, there are some things that can be done to control and regulate the deoxygenation factor, namely, diluting the sewage and reducing the concentration of sludge. However, possibilities in preventing bulking by the control of these factors are limited. The control of the oxygenation capacity can also be of value in this problem. The oxygenation capacity can be increased by increasing the air supply and the detention time. Neither of these expedients are practical or economical. The problem of prime importance is increasing the oxygen supply. An improvement can be made in the design of the distribution of air in the aeration tanks which at present allows only 5–10 per cent of the oxygen to be put into valuable use, when more of it is seriously needed. Although it is beyond the scope of this paper to make positive recommendation as to the design of aeration tanks, some of our observations regarding this question may be helpful. In the spiral flow type of aeration tank there seems ample opportunity for short circuiting. Some of the sludge will slip through the tank within a very short period of time, thereby creating partially under-aerated sludge, with a high oxygen consuming capacity. There is also a definite indication of an oxygen deficient core.[10] From these considerations it follows that if the same amount of air is put through more than one row of diffusers, especially if the rows of plates are spaced relatively far apart, some definite advantage in air distribution in the liquid may be obtained. The ideal solution would be to cover the entire tank bottom with diffusers without increasing the air input. If this could be done, not only bulking could be prevented, but purification rates could be increased to more nearly the maximum values obtained under laboratory conditions. This may not be practicable, but breaking the spiral flow without causing sludge deposition should be the aim to strive for. We do not believe that baffles are the perfect solution for this problem. Increasing the oxygenation capacity may also

be accomplished by keeping the air in the tank under pressure as attempted by Hicks.[3]

Kessener and Ribbius[7] contend that with suitable tests the dependence of purification capacity on oxygenation capacity can be shown. The basis of this contention is certain underlying biochemical principles and postulates. We would like to add that these very same biochemical principles and postulates that determine the purification capacity also determine the bulking phenomenon. In brief, if Kessener and Ribbius' postulates and discussion are compared with the discussion of underlying causes of bulking presented in this paper a startling similarity of concept will be observed. We have given evidence that bulking is associated with purification under conditions of oxygen deficiency and therefore it is due to the improper relation between oxygenation and purification capacities.

There are two tests which Kessener and Ribbius have developed for the determination of the efficiency of aeration systems. The first entails the determination of the purification capacity which is laborious and time consuming. According to the authors at least three months are required for accurate estimation of purification capacity of an aeration tank under one set of operation conditions. The second method which is simpler is dependent on the determination of oxygenation capacity. It is based on the rate of oxygenation of deoxygenated water and sewage in the aeration tank. This is presumably done on a batch process basis. The values therefore obtained are ultimate and maximum and not those that would be obtained under conditions prevailing with continuous flow with varying degrees of short circuiting. If on the other hand the test is run on the continuous flow basis, it would be difficult to evaluate the detention time in the estimation of the rate of oxygenation. The theoretical detention times at different points along the aeration tank operated on a continuous basis may vary within wide limits from the actual.

It might be suggested that a mere practical yardstick for determining the efficiency of aeration systems may be found indirectly in the phenomenon of bulking. This biological yardstick cannot be used in the design of the plant but only in the improvement of the operation after construction.

Summary and Conclusions

Bulking of activated sludge with sewage doses was accomplished experimentally under laboratory conditions by diluting the concentration of oxygen in the air with nitrogen gas. With quantities of oxygen comparable to that supplied in plant practice, bulking can be readily reproduced in the laboratory. The following factors have been found to be important in determining the rate of bulking:

1. With a given sewage load and sludge concentration the rate of bulking is dependent upon the quantity of air or its concentration in the gas mixture.

2. With a given sewage load and quantity of air the rate of bulking increases with increasing suspended solids concentration in the activated sludge mixture. With suspended solids beyond certain concentrations, the rate of increase in sludge index decreases.

3. A more highly oxidized sludge bulks less readily than a poorly oxidized sludge.

4. The addition of 10–20 p.p.m. nitrate nitrogen prevents bulking.

5. The stronger the sewage the more readily it causes bulking. Of the two methods of dosing with equal amounts of sewage load the more frequent additions of a dilute sewage results in the maintenance of the initial sludge index, while the less frequent addition of a stronger sewage gives an increase in the sludge index.

6. The higher the temperature the greater the increase in sludge index will be, provided the purification mechanism is not impaired by a deficiency of oxygen on account of the higher oxygen demand at the higher temperature.

7. Reaeration of sludge with a limited oxygenation capacity may result in an increase in sludge index especially with higher sludge concentrations.

Interpretation of these results involves a proper integration of various factors which can be summed up in terms of deoxygenation and oxygenation capacities. The deoxygenation is dependent on the total oxygen demand created by the mixture of activated sludge which in turn depends on the strength and volume of sewage, concentration and activity of the sludge and temperature. The oxygenation capacity is determined primarily by the design of the aeration tank, quantity of air, detention period, and temperature. Once an aeration tank is designed for a sewage flow of a given strength there is little that the operator can do in a fundamental way to avoid bulking. He can take certain curative measures such as reduction of sludge concentration, increasing the air supply if he has the compressor capacity and is not too interested in economy. Return of effluent or pumping of stream water can be resorted to with fair results. To the laboratory experimentors with activated sludge our results show that the rate of purification and oxidation with small volumes of mixture of activated sludge treated with normal air is far in excess of plant practice. This is due to the difficulty of maintaining the sludge in suspension with proportionate flows of air per unit volume of liquid. The expedient of diluting the air with nitrogen to obtain flows of oxygen similar to plant practice and obtain equal rates of purification is necessary before proper application of results to plant practice can be made.

In regard to the mechanism of bulking in the absence of carbohydrates the results definitely establish the deficiency of oxygen as the factor of prime importance. All other factors should be considered as contributory. When there is an oxygen deficiency, *Sphaerotilus,* which can grow both under aerobic and anaerobic conditions, becomes predominant over Zoogloea, which can grow only under aerobic conditions.

Oxygen deficiency should not be interpreted as the entire absence of oxygen for under these conditions there is no purification, little if any sludge build-up and hence no bulking. The supply of oxygen should be sufficient not to interfere with the purification mechanism and yet inadequate for complete aerobic stabilization.

Bulking in the presence of carbohydrates is also due to the preponderance of *Sphaerotilus* but not primarily through an oxygen deficiency created by the carbohydrates but as a direct specific food response. *Sphaerotilus* utilizes carbohydrates more efficiently and consequently causes a deficiency of food for Zooglea.

Bibliography

1. *Anon.* New England Association Reviews Sewage Research. *Mun. San.*, **10**, 592 (1939).
2. H. Heukelekian. II. Factors Influencing the Clarification of Sewage by Activated Sludge. This Journal, **9**, 431 (1937).
3. R. Hicks. The Effect of Pressure on the Rate of Oxidation of Sewage in the Presence of Activated Sludge. *Inst. Sew. Purif.*, Part II, 39 (1938).
4. R. S. Ingols and H. Heukelekian. Studies on Activated Sludge Bulking. I. Bulking of Sludge by Means of Carbohydrates. This Journal, **11**, 927 (1939).
5. R. S. Ingols and H. Heukelekian. Buffer Values of Sewage During Purification. *Ind. Eng. Chem.*, **32**, 401 (1940).
6. J. H. Kershaw and J. Finch. The Treatment of Diluted Sewage by Bioaeration in the Presence of Nitric and Nitrous Nitrogen. *Inst. Sew. Purif.*, Part II, 397 (1931).
7. J. N. H. Kessener and F. J. Ribbius. Comparison of Aeration Systems for the Activated Sludge Process. This Journal, **6**, 423 (1934). Also *Inst. Sew. Purif.*, Part I, 50 (1935).
8. F. W. Mohlman. The Sludge Index. This Journal, **6**, 119 (1934).
9. F. R. O'Shaughnessy and C. H. Hewitt. Phenomena Associated with the Rôle of Nitrogen in Biological Oxidation. *Inst. Sew. Purif.*, Part I, 221 (1935).
10. G. M. Ridenour and C. N. Henderson. Comparison of Sewage Purification by Compressed Air and Mechanically Aerated Activated Sludge. This Journal, **8**, 924 (1936).
11. C. N. Sawyer. Activated Sludge Oxidation. V. The Influence of Nutrition in Determining Activated Sludge Characteristics. This Journal, **12**, 3 (1940).
12. Water Pollution Research Board Report for 1939. Activated Sludge Process of Sewage Tretatment, p. 28.

TYPHOID BACTERIA IN SEWAGE AND IN SLUDGE

AN INVESTIGATION INTO THE HYGIENIC SIGNIFICANCE OF SEWAGE PURIFICATION IN THE TROPICS WITH REGARD TO TYPHOID FEVER

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Although typhus abdominalis occurs very generally throughout the whole world, both the morbidity and the mortality for this disease are definitely much higher in the tropics than in colder climates.

This is also the case in Netherlands India where, according to Winckel (1927), typhoid fever ranks first among the infectious diseases as a direct cause of death among Europeans.

Below, the figures for the incidence of typhus abdominalis among Europeans in Netherlands India are compared with the corresponding figures for the Netherlands for recent years. It will be seen that, at present, the typhoid fever figures for Netherlands India are 20 to 25 times greater than those for Holland.

Table I.—*Typhoid Fever Morbidity among Europeans in Netherlands India and the Netherlands*

Netherlands India		The Netherlands	
Batavia (1920–1934)	3.5%	(1920–1936)	0.14%
Soerabaya (1925–1936)	2.7%		

In considering all the agencies responsible for the occurrence of typhoid fever in this country we must, in the first place, pay full regard to the two principal factors which contribute to the prevalence of this disease, viz.: susceptibility and infection.

That a predisposition of the human body to infectious diseases in general should be greater in this country than in a colder climate is not surprising. Our physiological state is certainly not improved by the neurasthenic conditions which develop in many people after a stay in the tropics and which is ascribed by clinicians to the climate (Radsma 1932). The increase in body temperature, which rises above normal when the heat conditions of the atmosphere surpass the limits of comfort, has undoubtedly an unfavorable effect on our physical powers of resistance. The blood circulation in the periphery of the body is intensified by heat, and this causes a lessening in the circulation internally, which in a certain measure paves the way for infection of the internal organs by intestinal parasites.

It is, therefore, beyond question that, generally speaking, in a tropical climate our resistance to harmful influences is lower.

With reference to infection, we must consider the primitive hygienic conditions prevailing in this country. These conditions undoubtedly bring us into more widespread and closer contact than in Holland with the nidus of typhoid fever, viz.: human fecal matter.

On further consideration of the infection-factor it might be thought that on account of the high temperatures the typhoid bacteria would have a greater viability, enabling them to survive longer in surface-waters and in the soil than is the case in more temperature climates. Investigations into this matter, however, all point to a decreased viability of typhoid bacteria in the tropics. For example, whereas in Belfast Wilson and Blair (1931) could isolate typhoid bacteria from sewage which had stood in the laboratory for five weeks, in Calcutta, Stewart and Ghosal (1932–33) found that these organisms had disappeared completely from sewage and feces within one week.

That higher temperatures work towards the destruction of typhoid bacteria has also been shown by Ruchhoft and Charlotte Ruys. Ruchhoft (1934) found that these organisms had an extreme life-limit of a fortnight when conserved in activated sludge at a temperature of 20 to 22° C. By keeping the temperature of the sludge at 10 to 15° C., however, he could still isolate typhoid bacteria after 83 days. Charlotte Ruys (1936) proved that in canal water kept for 6 days at 24° C. all bacteria were dead, whereas in water kept at 6° C. for the same time live bacteria could still be isolated.

Bearing in mind that in tropical nature the sun—excluded in these laboratory experiments—also plays an important role in the removal of bacteria (Holwerda 1928), we are apt to think that the greater prevalence of typhoid fever is not a consequence of tropical conditions favorable to the bacteria but is due to a greater number of the typhoid bacteria existing among us, in spite of the strongly destructive influences to which they are exposed.

The low typhoid fever frequency in Europe and America is, moreover, a phenomenon of recent times. Not many years ago the figures for these countries were at least as high as they now are for the tropics. Taking as an example Pennsylvania (U. S. A.) we see that, as late as 1906, the morbidity was 3.4 per cent but that in 1934 it had declined to 0.1 per cent (Moses 1936).

As an European example we may cite the Province of Noord-Holland where the morbidity fell from 5.6 per cent in 1903 to 0.69 per cent in 1936 (Report for 1936 of the Prov. Waterleidingbedrijf van Noord-Holland). Here, too, we see a considerable decline, though for this district the figures are noticeably higher than for the whole of Holland, where we find a morbidity of 0.53 per cent in 1903 against only 0.03 per cent in 1936.

It is presumed—and most certainly with justification—that the reduction in the incidence of typhoid fever is, for the greater part, to be ascribed to the construction of sanitary works, more especially water-works and sewerage systems. As a general rule it is to be observed that in places where hygienic conditions are primitive, even now, higher

typhoid fever figures are to be found (*e.g.* S.E. Europe). On the other hand in those places where sanitary measures in connection with waterworks have been vigorously taken in hand, typhoid fever has fallen off in the last 30 to 40 years by about 90 per cent.

It is, therefore, obvious that a connection should be sought between the comparatively high typhoid fever morbidity in Netherlands India and the existing status of water supplies and sewage disposal.

The drinking-water supplies in Netherlands India have been considerably extended during the last 20 years. In 1920 there were 45 general water supplies in use in the whole Netherlands Indian Archipelago; nowadays, more than 250 municipalities and other communities are supplied with reliable drinking-water. Many of the waterworks that were in existence have been considerably improved and enlarged during that period.

The question as to whether these water supplies have contributed to the decrease of the risks of typhoid fever was answered affirmatively by Snuyf (1937) with the statistical material at his disposal. He calculates that, while in Soerabaya there was a hygienic system of water distribution in the form of a well-water supply, in Batavia there existed a very deficient, unhygienic artesian-water supply, and the typhoid fever morbidity amongst the Europeans in Soerabaya at that time was only 45 per cent of that for the corresponding group in Batavia. He reports further that in Batavia, where the waterworks were completed in 1922, the typhoid fever morbidity fell from 5 per cent for the period 1917–1922 to 3.9 per cent for the period 1923–1928. Moreover, even subsequent to 1928 the continued extension of the waterworks in Batavia was marked by a further fall in the typhoid morbidity.

Thus in this country, too, the universal parallel between improvements in the quality of water supplies and a decrease in typhoid fever is confirmed by statistics, not only in the positive but also in the negative sense.

Walch (1934) studied the typhoid fever statistics of a town with an inferior water supply, viz.: Cheribon, as shown by the typhoid fever morbidity for that place, which was 6.3 per cent amongst the Europeans in the years 1926–1932. This fitted remarkably with the quality of the water supply, which in nowise satisfied hygienic demands. In the course of 1938, however, the waterworks were completely reconstructed and there is now a mountain spring-water supply, furnishing entirely reliable drinking water.

The removal and treatment of sewage in Netherlands India is in a much inferior stage of development to that of the supply of drinking water.

In view of the dense population, the construction of central sewerage systems would be very costly for most of Netherlands Indian towns. Advantage has, therefore, to be taken of other means of refuse destruction and here the septic tank stands out most prominently.

Although these have become very popular in Netherlands India, it gradually is becoming apparent that this type of installation does not,

after all, entirely achieve its object, *i.e.* purification of sewage, whereby the soil into which the effluent is discharged is safeguarded against pollution (Mom and Schaafsma 1932).

Leaving aside here the question of chemical purification, we would point out only the fact that the contents of a septic tank cannot nearly be freed of pathogenic organisms.

With regard to typhoid bacteria, this was convincingly shown in Calcutta by Stewart and Ghosal (1932–33) who, out of 25 samples of septic tank effluent, isolated typhoid bacteria in 20.

That in a tropical town without a sewerage system the number of typhoid bacteria spread, either directly or via septic tanks, can be enormous was shown by Dinger (1937) at Batavia. The river there, the Tjiliwoeng, with many ramifications from wash-water channels, flows through the town and, in the absence of a sewerage-system carries all the surface-water, part of the ground-water and very great quantities of refuse to the sea and in its water Dinger could regularly demonstrate typhoid bacteria.

In total he examined 103 samples, taken from the Tjiliwoeng at 20 different places and in only one single place could no typhoid bacteria be found (10 samples, totalling 73 c.c. of water). At all other places from which samples were taken typhoid bacteria were shown once or even several times. Out of 478.15 c.c. of water 74 strains were found, *i.e.* an average of 1 bacterium per 6½ cm.^{3} of water.

Furthermore, Dinger also found that of a suspension of typhoid bacteria inoculated into a nutrient medium prepared according to Wilson and Blair, the number to grow was only 2 to 12½ per cent (average 9 per cent) of the number developing in broth. The number of live bacteria in the water examined must, therefore, be considerably higher than the number isolated on the Wilson and Blair plates.

Considering that a great part of the native population bathes and washes—even to rinsing the mouth—regularly in this river it can hardly be doubted that the presence of such a typhoid reservoir in the very midst of densely populated sections of the town must influence the prevalence of the disease.

In the light of these results it seemed important to trace the fate of typhoid bacteria in a town that possesses at least a partial sewerage-system. This opportunity was found at Bandoeng.

This town has a total area of 10.8 sq. miles and a population of 200,000; a part, 0.46 sq. miles, occupied by a population of about 40,000 is sewered, while it is proposed, during the next few years, to extend the sewers to a further 1.5 sq. miles. Purification of the sewage is now attained by passing it through an Imhoff-tank installation where the suspended particles settle and digest. The installation now in use has been described by Mom and Thysse (1935).

The flow of the main sewer, where it discharges into the Imhoff-tank installation, is 1,590,000 gallons per 24 hours. The sewage is freed in the tank of its coarse particles and then flows into the Tjitepoes, a small

river of which the dry weather flow does not exceed 1,320,000 gallons per day.

The sewage of the suburbs not supplied with a sewerage system is conducted in open canals to the many little rivers traversing the town, one of which is also the Tjitepoes. Before receiving the effluent of the Imhoff tank this river flows through Bandoeng and in its course traverses suburbs connected to the sewerage system as well as some where it is not yet installed.

Typhoid Bacteria in Surface-water

Considering that the water of the Tjitepoes, before receiving sewage may be regarded as truly representative of Bandoeng's surface-water, samples of the water of this stream were regularly taken at a point about 50 metres above the sewer outlet and these were examined for typhoid bacteria.

Since, at this point, the river water drops over a weir some 6 ft. high and the samples were all taken above this sill, there is no danger of sewage contaminating the water examined.

The oxygen consumed from permanganate in the river water at this point is about 50 mg./l., while *B. coli communis* (Eijkman's test) is present in 0.01 to 0.001 c.c.

The examination of this water for typhoid bacteria was done by mixing a quantity of the water with melted agar-medium, according to Wilson and Blair (1927, 1931), and then pouring the mixture on plates. Bacteria growing in black colonies were transferred to Endo plates containing lactose and saccharose. Those strains which formed white, transparent colonies thereon were examined for motility, for gram-staining, for fermentation of glucose, maltose and mannitol, for indol-forming from tryptophane, and for agglutination with a typhoid serum. Gram-negative rods which showed typical growth on the Wilson-Blair and Endo media, being motile, acid-forming from glucose, maltose and mannitol, producing no indol, and agglutinating to full titre with a typhoid serum were regarded as typhoid bacteria. The properties of a number of the strains thus isolated, were controlled at the Queen Wilhelmina Institute for Hygiene and Bacteriology in Batavia and at the Pasteur Institute in Bandoeng.

The Wilson and Blair's method of isolation worked very satisfactorily in the examinations described below. The preparation of the nutrient-medium and the operations of inoculating and isolating, however, demand more than ordinary care on the part of the examiner. The directions must be followed very exactly and it is only after considerable practice in the technique that results—often anomalous at the beginning—become regular.

The results of the examinations of the Tjitepoes water are shown in Table II.

In 11 out of the 44 samples examined typhoid bacteria were found. The total volume of water was 124.5 c.c. and the number of strains isolated was 17, thus making an average of 1 typhoid bacterium per 7.3 c.c.

TABLE II.—*Typhoid Bacteria in River Water in Bandoeng*

Date of Examination, 1937–38	Volume of Water Examined in c.c.	Number of Typhoid Strains Isolated
December 18	1	1
December 27	1	0
January 3	2	0
January 10	2	5
January 24	2	0
January 31	2	2
February 8	2	0
March 7	2	1
May 3	2	0
May 4	2	0
May 5	2	0
May 16	2	0
May 17	2	1
May 19	2	0
May 21	2	0
May 28	2	0
June 4	2	0
June 7	2	0
June 8	2	0
June 9	2	0
June 11	2	0
June 14	2	1
June 15	2	0
June 16	2	0
June 20	2	0
June 21	2	1
June 22	2	0
June 25	2	0
June 28	2	0
June 30	2	0
July 7	2	0
July 9	2	0
July 11	2	0
July 13	5	0
July 19	5	2
July 22	5	1
July 25	2.5	0
July 27	2.5	0
July 30	7.5	0
August 2	5	0
August 8	7.5	0
August 10	7.5	1
August 20	7.5	1
August 24	5.5	0
Total of 44 samples	124.5 c.c.	17 strains

of water. This average figured from a relatively small number of strains isolated, agrees fairly well with the extensive data collected by Dinger on the prevalence of typhoid bacteria in the Tjiliwoeng. The results of this investigation into the Tjitepoes water seem to indicate

that the occurrence of typhoid bacteria in the river-water at Bandoeng is of the same numerical order as at Batavia.

It would be of little use to make more detailed comparisons of the occurrence of typhoid bacteria in the two rivers because, although the Tjiliwoeng and the Tjitepoes have much in common, both as regards their courses and basins, they cannot be compared in detail. Of both rivers the flows, which directly respond to the rainfall in their respective basins, vary considerably and so infection by typhoid bacteria through fecal matter must change, quantitatively, from moment to moment. Both rivers traverse densely populated areas, but the Tjiliwoeng drains a greater surface than the Tjitepoes and thus has greater chances of being infected; on the other hand, the Tjiliwoeng, on an average, carries off much more water, giving a greater dilution of the infection.

Typhoid Bacteria in Sewage

An investigation was made of the occurrence of typhoid bacteria in sewage (—oxygen consumed from permanganate 200 to 300 mg./l., *B. coli* present in 1×10^{-6} c.c.). At first, difficulties were encountered caused chiefly by the presence in the sewage of saprophytes which grew in black colonies on the Wilson and Blair medium. Not only were these difficult to distinguish from typhoid bacteria but sometimes they occurred on the plates in such quantities that they entirely suppressed the growth of the typhoid bacteria. These organisms have already been described by Wilson and Blair (1931) who were troubled with them in Europe, especially in summer.

Probably as a consequence of the tropical climate, these organisms occur in the Bandoeng sewage very often. It is, therefore, necessary to dilute the sewage considerably before examination, in order to avoid the growths on the plates becoming too dense. In the course of the investigation it transpired that the addition of alcohol to the medium recommended by Wilson and Blair (1931) had favorable results. The growth of colonies of black saprophytes was effectively counteracted by alcohol. An addition of 2 c.c. of alcohol per 100 c.c. of medium, as recommended by these authors, however, proved a serious impediment to the growth of the typhoid bacteria, too, in our medium. Using 1 c.c. of alcohol to 100 c.c. of medium, however, gave very satisfactory results which are shown in Table III. This also contains the results of examinations of sewage in Wilson and Blair's medium without alcohol and in the same medium with the addition of 1 per cent alcohol.

While the number of black colonies considerably decreased on the addition of alcohol, the number of typhoid bacteria isolated on the medium containing alcohol was not less, but rather more than in the control tests.

That this favorable result was not a consequence of a better growth of the typhoid bacteria through the addition of alcohol was shown in some experiments in which a diluted suspension of a pure-culture of typhoid bacteria was counted, using broth-agar, Wilson and Blair's

TABLE III.—*Comparative Investigation into the Influence of Alcohol in the Isolation of Typhoid Bacteria from Sewage*

Sample	Without Alcohol		With Alcohol per 100 c.c. Wilson and Blair's Medium	
	Number of Black Colonies per c.c.	Number of Typhoid Bacteria Isolated per c.c.	Number of Black Colonies per c.c.	Number of Typhoid Bacteria Isolated per c.c.
1	2000	4	130	6
2	2180	2	174	2
3	6000	14	320	42
4	1732	12	240	8
5	3000	3	300	2

agar, and Wilson and Blair's agar plus alcohol, respectively. From the results of these agar-counts, which are set out in Table IV, it appears that the typhoid bacteria are more strongly impeded by the alcohol in the last-named medium than in the usual Wilson and Blair one. The favorable result of using alcohol in the isolation of typhoid bacteria is thus to be attributed exclusively to the still stronger inhibition of the saprophytes forming black colonies.

TABLE IV.—*Number of Bacteria Present in 1 c.c. Suspension of a Pure Culture of B. typhosum, Counted in Different Agar Media*

Test	Number of Typhoid Colonies per c.c. Growing in:		
	Broth-agar	Wilson and Blair Agar	Wilson and Blair-agar +alcohol
1	170	105	69
2	114	85	67
3	79	58	36
4	98	69	46
5	118	26	23
6	332	75	46
7	203	93	78

Of the crude sewage of Bandoeng 80 samples were examined in total. The results are tabulated in Table V, which also contains the results of the examination of the Imhoff-tank effluent, discussed later.

Typhoid bacteria were found present in 62 samples of sewage. In total 7.21 c.c. of sewage were used. From this quantity 353 typhoid strains were isolated, giving an average of 49 typhoid bacteria per c.c.

The number of bacteria found in the different samples varied from less than 10 to 450 per c.c.

The difference between the typhoid prevalence in sewage and in river water is very striking. The sewer evidently acts as a very effective "trap" for the typhoid bacteria. Considering that the bacteria originate in human fecal matter, it is only natural that in a sewered quarter where household sewage is discharged into the sewer, by far the greater part of the typhoid bacteria generated in the living-quarters

will be caught in the sewer. Once there they are under our control and can be rendered harmless by suitable sewage purification.

From the great numbers of typhoid bacteria found at Bandoeng and Batavia in water polluted by feces, the high typhoid morbidity is understood. It is rather remarkable that the disease does not occur even more frequently.

For a comparison of these results with those of similar investigations made elsewhere, some data collected by others on the prevalence of typhoid in sewage are treated here in extract. In the tropics an investigation was made at Calcutta by Stewart and Ghosal (1932–33) who found typhoid bacteria in 20 out of 30 6 c.c.-portions of sewage. Further data relating to sewage in the tropics have not come to our notice.

Of the investigations made in Europe, those by Wilson and Blair (1931) are the most complete. In 1928 and 1929 they examined 15 samples of sewage from Belfast. Twelve of these were positive for typhoid. In total, 108 strains were isolated from 70½ c.c. of sewage, so that on an average 1 to 2 typhoid bacteria were found per c.c. The maximum was 5 to 6 in one sample. In 1929 and 1930, 24 samples were

TABLE V.—*Typhoid Bacteria in the Sewage of Bandoeng*

Date of Test	Sewage			Imhoff-tank Effluent		
	Volume Examined in c.c.	Number of Typhoid Strains Isolated	Number of Bacteria per c.c.	Volume Examined in c.c.	Number of Typhoid Strains Isolated	Number of Typhoid Bacteria per c.c.
May 5	0.1	2	20	—	—	—
May 16	0.1	2	20	—	—	—
May 17	0.1	1	10	—	—	—
May 19	0.1	1	10	—	—	—
May 21	0.1	0	<10	—	—	—
May 28	0.1	1	10	—	—	—
June 4	0.1	0	<10	—	—	—
June 7	0.1	1	10	—	—	—
June 8	0.1	0	<10	—	—	—
June 9	0.1	0	<10	—	—	—
June 11	0.1	0	<10	—	—	—
June 14	0.1	1	10	—	—	—
June 15	0.1	0	<10	—	—	—
June 16	0.1	1	10	—	—	—
June 20	0.1	1	10	—	—	—
June 21	0.1	1	10	—	—	—
June 22	0.1	2	20	—	—	—
June 25	0.1	2	20	—	—	—
June 28	0.1	0	<10	—	—	—
June 30	0.1	9	90	—	—	—
July 7	0.06	4	67	—	—	—
July 8	0.01	3	300	—	—	—
July 9	0.07	2	29	—	—	—
July 11	0.1	0	<10	—	—	—
July 13	0.05	2	40	0.05	1	20

TABLE V.—*Continued*

Date of Test	Sewage			Imhoff-tank Effluent		
	Volume Examined in c.c.	Number of Typhoid Strains Isolated	Number of Bacteria per c.c.	Volume Examined in c.c.	Number of Typhoid Strains Isolated	Number of Typhoid Bacteria per c.c.
July 19	0.05	2	40	0.5	8	16
July 22	0.05	0	<20	0.5	1	2
July 25	—	—	—	0.5	2	4
July 27	0.04	18	450	0.45	7	16
July 30	0.08	2	25	0.75	8	11
Aug. 2	—	—	—	0.5	1	2
Aug. 3	0.05	4	80	—	—	—
Aug. 4	0.07	4	57	—	—	—
Aug. 8	0.05	0	<20	0.3	3	10
Aug. 10	0.05	4	80	0.5	2	4
Aug. 11	—	—	—	0.5	4	8
Aug. 14	0.05	3	60	—	—	—
Aug. 15	0.02	7	350	—	—	—
Aug. 18	—	—	—	0.75	4	5
Aug. 20	0.03	1	33	0.5	2	4
Aug. 23	0.03	0	<33	—	—	—
Aug. 24	0.1	2	20	0.5	2	4
Aug. 25	0.05	7	140	—	—	—
Aug. 26	0.05	0	<20	—	—	—
Aug. 27	0.05	3	60	—	—	—
Sept. 12	—	—	—	0.5	2	4
Sept. 13	—	—	—	0.5	1	2
Sept. 17	0.05	3	60	0.25	15	60
Sept. 19	0.05	1	20	0.25	3	12
Sept. 20	0.1	3	30	—	—	—
Sept. 21	—	—	—	0.6	2	3
Sept. 26	0.05	3	60	—	—	—
Sept. 28	0.05	15	300	—	—	—
Nov. 12	0.1	0	<10	0.5	1	2
Nov. 15	0.1	1	10	0.5	6	12
Nov. 16	0.1	0	<10	0.5	9	18
Nov. 17	0.1	0	<10	0.5	0	<2
Dec. 5	0.1	2	20	0.5	11	22
Dec. 7	0.1	3	30	0.5	1	2
Dec. 8	0.1	8	80	0.5	2	4
Dec. 14	0.1	2	20	0.5	1	2
Dec. 20	0.1	6	60	—	—	—
Dec. 28	0.1	44	440	—	—	—
Dec. 30	0.1	3	30	—	—	—
Dec. 31	0.1	4	40	—	—	—
Jan. 4	0.1	4	40	—	—	—
Jan. 9	0.1	0	<10	—	—	—
Jan. 10	0.1	1	10	—	—	—
Jan. 14	0.1	37	370	—	—	—
Jan. 16	0.1	23	230	—	—	—
Jan. 19	0.1	3	30	—	—	—
Feb. 2	0.1	27	270	—	—	—
Fev. 13	0.1	6	60	—	—	—
Feb. 14	0.1	1	10	—	—	—

TABLE V.—*Continued*

Date of Test	Sewage			Imhoff-tank Effluent		
	Volume Examined in c.c.	Number of Typhoid Strains Isolated	Number of Bacteria per c.c.	Volume Examined in c.c.	Number of Typhoid Strains Isolated	Number of Typhoid Bacteria per c.c.
Feb. 15	0.1	1	10	—	—	—
Feb. 16	0.1	4	40	—	—	—
Feb. 17	0.1	4	40	—	—	—
Feb. 18	0.1	5	50	—	—	—
Feb. 21	0.3	10	33	0.3	9	30
Feb. 27	0.3	17	57	0.3	19	63
Mar. 3	0.1	10	100	—	—	—
Mar. 14	0.1	6	60	—	—	—
April 1	0.1	0	<10	—	—	—
April 14	0.1	0	<10	—	—	—
May 8	0.1	1	10	0.5	1	2
May 12	—	—	—	0.1	1	10
May 17	0.1	1	10	—	—	—
May 20	—	—	—	0.5	3	6
May 23	—	—	—	0.1	1	10
May 24	—	—	—	0.5	3	6
June 3	—	—	—	0.35	2	6
June 8	—	—	—	0.1	1	10
June 12	—	—	—	0.15	5	33
June 13	0.1	1	10	—	—	—
June 14	—	—	—	0.6	4	7
June 15	—	—	—	0.1	1	10
June 16	—	—	—	0.6	4	7
June 17	—	—	—	0.1	2	20
June 20	—	—	—	0.6	15	25
June 21	—	—	—	0.1	1	10
June 22	—	—	—	0.6	4	7
June 23	—	—	—	0.6	15	25
June 24	—	—	—	0.6	7	12
Total	7.21 c.c.	353 strains 80 samples	49 per c.c.	19.2 c.c.	197 strains 45 samples	10 per c.c.

examined each consisting of 1 c.c. of Belfast sewage. Of these 14 samples were positive and supplied 66 typhoid strains, an average of 3 strains per c.c. A maximum of 13 bacteria per c.c. was found in one sample.

Other investigations, on a smaller scale, nearly all done in England * gave results not differing essentially from the data collected by Wilson and Blair. Worthy of mention especially, is the investigation of Newman (1932), who found 60 and 40 typhoid bacteria respectively, in 2 samples of sewage each of 1 c.c. For Europe these figures are very high indeed.

The difference between the occurrence of typhoid bacteria in the sewage of Belfast and that of Bandoeng is very large. This is quite proportionate to the incidence of typhoid fever in both places. Belfast,

* Summarized in *Water and Water Engineering*, **35**, 595 (1933).

after all, is practically typhoid-free, whereas in Bandoeng it occurs endemically. In 1938 the typhoid morbidity for the European population of Bandoeng was 2.90 per cent, while the total typhoid morbidity for that year was 1.78 per cent (statistically the latter figure is considerably less reliable than that for Europeans only).

It may, therefore, be expected that in all probability, with the effective removal of household-waste by way of sewers, combined with purification, the typhoid figures for Netherlands India will fall off considerably.

Purifying Capacity of Imhoff Tank

It seemed important to trace the effect of sedimentation in the Imhoff tank on the occurrence of typhoid bacteria. Their fate will depend mainly on the form in which they get into the sewage. They can in fact occur in solid refuse (feces) and in liquids (urine). Since feces settle in the tank, the fecal bacteria will, to a great extent, remain there but the bacteria from urine will pass unhampered. Of the bacteria from feces a good many will also pass the digestion-chamber since, in the tropics, feces before settling drift on the surface for some time and then disintegrate. During this process part of the bacteria present may pass into the liquid sewage.

The investigation comprised 80 samples of sewage (tank influent) and 45 samples of tank effluent. The results are given in Table V.

From this table it will be seen that from only one effluent sample could no typhoid bacteria be isolated. The number of positive samples was thus proportionately much greater in the effluent than in the sewage.

From the total of 19.2 c.c. of effluent examined, 197 strains could be isolated, making an average of 10 typhoid bacteria per c.c. The number of bacteria found in different samples varied from less than 2 to 63 per c.c.

Considering that the average figures for typhoid bacteria before and after passing through the tank are 49 and 10 respectively per c.c., an average of 39, or 80 per cent of the original, should be the number of typhoid bacteria remaining behind in the tank. As, however, not all the figures in Table IV refer to the influent and effluent of the tank on one and the same day, we took only the period from 13th July to 14th December 1938 inclusive, during which the sewage before and after the tank was very regularly examined, for a closer investigation into the effects of sedimentation.

Of the sewage entering the tank 30 samples were examined and of the effluent 25 samples. Out of a total of 1.97 c.c. of sewage before the tank 100 typhoid strains were isolated and out of 12.4 c.c. of effluent, 99 strains. The number of bacteria before the tank thus averaged $100/1.97 = 51$ per c.c., and after, $99/12.4 = 8$. On an average, therefore, 43 bacteria, or 80 per cent of the original number remained in the tank. This result appears to coincide with that for the whole period.

In order to ascertain whether the considerable decrease of typhoid

bacteria in the sewage during its passage through the tank is a result of sedimentation or whether other factors contribute—*e.g.* death of the pathogenic organisms in what is for them an unfavorable milieu—the decrease in other bacteria was investigated.

With this object the total numbers of organisms growing in black colonies on the Wilson and Blair agar were also counted in the sewage for the period July 13 to December 12, 1938. Table VI gives the results of these counts. On an average the number of bacteria on the Wilson and Blair agar before the tank was 4063 and after it 1194.

Thus on an average 4294 bacteria per c.c., or 78 per cent of the original number remained in the tank. The decrease in the total num-

TABLE VI.—*Total Number of Bacteria per c.c. in Sewage, Forming Black Colonies on Wilson and Blair Agar*

Date of Examination 1938	Sewage	Imhoff Tank Effluent
July 13	6,000	800
July 19	10,400	1,450
July 22	5,600	780
July 25	—	232
July 27	3,900	620
July 30	1,000	374
August 2	—	150
August 3	1,340	—
August 4	3,960	—
August 8	1,600	570
August 10	4,200	1,040
August 11	—	390
August 14	2,500	—
August 15	20,000	—
August 18	—	96
August 20	10,000	330
August 23	6,800	—
August 24	5,580	2,100
August 25	6,200	—
August 26	1,000	—
August 27	1,380	—
September 12	—	2,000
September 13	—	2,400
September 17	30,000	6,000
September 19	3,380	1,732
September 21	—	3,500
September 26	1,720	—
September 28	4,180	—
December 5	970	206
December 7	800	164
December 8	1,600	190
December 14	2,960	1,040
Average	5,483	1,189
Total	25 samples	22 samples

ber of organisms growing on the Wilson and Blair plates occurs, therefore, in the same proportion as the decrease in the typhoid bacteria. Since typhoid bacteria react in the same manner as saprophytes, it would appear that, here, one may rightly speak of a *mechanical* purification in the Imhoff tank.

In order further to confirm this opinion, sewage was allowed to settle for 2 hours in Imhoff cones. Before and after settling the numbers of typhoid bacteria as well as the total number of all bacteria growing on the Wilson and Blair plates were determined. The results of ten tests are given in Table VII.

TABLE VII.—*Typhoid Bacteria and Total Number of Bacteria (Wilson and Blair Agar) in Sewage and Sludge after 2-Hour Settling in Imhoff Cones*

Sample	Sewage before Settling		Sewage after 2-Hour Settling		Sludge	
	Number of Typhoid Bacteria per c.c.	Total Number of Bacteria per c.c. (W. & B. Agar)	Number of Typhoid Bacteria per c.c.	Total Number of Bacteria per c.c. (W. & B. Agar)	Number of Typhoid Bacteria per c.c.	Total Number of Bacteria per c.c. (W. & B. Agar)
1	440	1810	110	864	540	51,200
2	30	4000	14	768	120	—
3	40	2680	12	688	100	18,020
4	40	7320	14	1760	—	∞
5	<10	3080	14	968	—	48,000
6	10	1900	4	640	—	∞
7	370	3280	46	800	—	21,600
8	230	1150	138	568	200	18,400
9	30	1020	12	680	500	52,800
10	270	2020	114	848	700	79,200
Average	146	2826	48	858		

Since the number of typhoid bacteria per c.c. was 146 before and 48 after settling, an average of 98 per c.c., or 67 per cent of the original number, settled.

From the figures for the total numbers of bacteria growing on the Wilson and Blair agar it can be calculated that 2826 — 858 = 1968 per c.c., or 70 per cent of the original numbers settled.

Thus these experiments, too, showed good agreement between average counts of typhoid bacteria and total numbers of bacteria growing on Wilson and Blair agar.

It must, however, be mentioned that for *individual* samples the agreement was often not quite so good (samples 1, 2, 9). The percentage of the original number of bacteria to disappear during the settling period varied for typhoid between 40 and 88 per cent and for all bacteria on Wilson and Blair agar between 33 and 81 per cent.

These figures give the impression that purification in the settling glasses is somewhat less efficient than in the Imhoff tank. This can be explained, because in the glasses the sewage remains stationary while in the tank it flows slowly through. This flowing may well be the reason

that a portion of the colloids flocculates (Rudolfs and Gehm 1937) and in doing so, carry away bacteria.

That actually a great part of the typhoid bacteria in the sewage are bound to the coarse floating particles may also be seen from tests of filtration of sewage through sterile cotton wool. A typical result of such filtration is given below in Table VIII.

TABLE VIII.—*Sewage Before and After Filtration through Sterile Cotton Wool*

	Sewage	Sewage After Filtration
B. typhosum per c.c.	80	30
B. coli (Eijkman) per c.c.	1,700,000	325,000
Number of bacteria (broth-agar) per c.c.	4,850,000	2,700,000
Turbidity (mgr./l. SiO_2)	390	144
Solid matter (mgr./l.)	523	368
Solid matter after ignition (mgr./l.)	255	214

It may thus be concluded that a great part of the typhoid bacteria settle in the Imhoff tank with the coarse floating particles; that probably a smaller part is carried away with the flocculating colloids, and that in this manner, roughly speaking, 80 per cent of the typhoid bacteria in the sewage are caught by the tank.

Although this result may certainly be regarded as favorable we cannot overlook the fact that sewage with an average of 10 typhoid bacteria per c.c., such as this effluent contains, must, of course, be still regarded as a dangerous fluid which in most cases should undergo further treatment before discharge. In simply allowing the sewage to flow into open water the pathogenic bacteria, which are first carefully caught in the sewer, are again released. Only in special instances might this be permissible, *e.g.* where, far from populous areas, sewage can be discharged into a large river or lake or into the sea where natural purification is so great that the bacteria are destroyed before they can return to centres of human habitation. In the nature of things this procedure can be employed only in certain cases; the other and safer way one may, in most cases must, choose, is to account for the bacteria themselves. With this object the sewage must be subjected to further purification for which we have several efficient technical means at our disposal.

TYPHOID BACTERIA IN SLUDGE

The typhoid bacteria that settle in the tank, together with the sludge, reach the digestion chamber. In order to ascertain the fate of these organisms during the digestion of the sludge some samples of fresh sludge were first investigated. The result was as follows (Table IX):

These results were very much lower than might be expected in view of the previous observations. Calculating that 40 typhoid bacteria settle per c.c., then 40,000 bacteria per litre of sewage should pass into the sludge.

TABLE IX.—*Examination of Fresh Sludge for Typhoid Bacteria*

Date of Sample, 1939	Typhoid Bacteria per c.c.
March 8	10
March 14	24
April 1	0
April 14	2
May 8	2
May 17	0
June 13	2

From a litre of sewage about 10 c.c. of sludge is separated and so the occurrence of typhoid bacteria in the sludge should amount to 40,000/10 = 4000 per c.c. The actual numbers found deviate very considerably from this figure.

A similar result was obtained during the settling tests in Imhoff cones mentioned above. After settling the numbers of typhoid bacteria per c.c. and of all bacteria growing on the Wilson and Blair agar, were determined (Table VI). From these data it could be calculated how many bacteria should settle in the sewage. This number should be commensurate with the number of typhoid bacteria recovered in the sludge but, as is shown in Table X, this is not the case.

TABLE X.—*Number of Typhoid Bacteria Settled in 1 Litre of Sewage and Number Recovered in Sludge, Calculated from Data of Table VII*

Sample	Typhoid Bacteria		Total Number of Bacteria (Wilson and Blair Agar)	
	Settled in Sewage	Recovered in Sludge	Settled in Sewage	Recovered in Sludge
1	330,000	8,100	946,000	768,000
2	16,000	1,200	3,232,000	—
3	28,000	1,000	1,992,000	180,200
4	26,000	0	5,560,000	∞
5	—	0	2,112,000	528,000
6	6,000	0	1,260,000	∞
7	324	0	2,480,000	216,000
8	92,000	1,400	582,000	128,800
9	18,000	3,750	340,000	396,000
10	156,000	3,500	1,172,000	396,000

In four instances no typhoid bacteria whatever were isolated from the sludge, while in the other six samples the numbers were again much lower than the calculated number of settled bacteria. In this connection a dying off of the typhoid bacteria might occur, but such a marked decrease in the course of only 2 hours seems hardly probable. Against this supposition is the fact that the total numbers of bacteria growing on Wilson and Blair agar were also smaller, in most cases, than the calculated numbers.

An immediate reason is to be found for the failure to isolate typhoid bacteria from the sludge of Samples 4 and 6. Here the agar-plates

inoculated with sludge were too densely overgrown. As is well known (Wilson and Blair (1931), Dinger (1937) and many of our own observations) when this occurs the typhoid bacteria cannot develop because of the antagonistic action of the other organisms.

For samples 5 and 7, however, we cannot equally attribute this reason as, here, the plates were not too densely overgrown. Nor can we assume that some poisonous matter possibly might be present in the sludge, which could unfavorably affect the growth of the typhoid bacteria because the sludge-concentration (0.01 to 0.05 c.c. to 100 c.c. Wilson and Blair agar) was too low for this.

These results call for an explanation which we find in the following considerations:

Typhoid negative results were found in the 45 samples of tank effluent examined (Table V), only one, in the 80 samples of sewage (Table V), 18 and in the 17 samples of sludge (Tables IX and X) 6.

The average total number of all bacteria, however, shows a contrary classification; the number of bacteria in the effluent samples was lowest and in the sludge samples highest. The sewage occupies an intermediate position between effluent and sludge both as regards the number of general organisms and the number of typhoid bacteria found.

For the sewage it was shown that the majority of typhoid bacteria adhere to floating particles. Since the sludge is built up from these complexes, this material is actually a concentration of typhoid bacteria.

This picture is, however, not reflected by the Wilson and Blair plates. The more solid particles the samples examined contained, the fewer were the typhoid bacteria isolated. This occurrence was very strongly accentuated in the sludge examination where no fewer than 35 per cent of the samples were found to be typhoid-negative.

The possibility of isolating typhoid bacteria by the method adopted, thus appears actually to be governed by the habitus of the micro-milieu of the typhoid bacteria proper. They are most easily detected in the most watery milieu and with greatest difficulty in the most solid material. In this connection it is significant that the solid particles composing the settled sludge have a more compact structure than the floating sludge particles, in consequence of the flocculation of the colloids during settling.

All sludge particles which contain typhoid bacteria will, naturally, also be rich in a great number of other varieties and the probability that amongst these organisms there are those which work inimically to the typhoid bacteria on Wilson and Blair agar is very great indeed. If such a sludge particle is introduced on to Wilson and Blair agar, the typhoid bacteria, due to the inhibitory action of other bacteria growing in their immediate neighborhood, will have no chance of developing and consequently, will not be disclosed in the test. The relation between the typhoid bacteria and their antagonists is probably closest in the settled sludge particles and therefore the results of the sludge examinations lead to the conclusion that many typhoid bacteria remain embedded in

the sludge particles and as a direct consequence of this, are not to be found on the Wilson and Blair plates.

Further consideration of this conclusion leads to the following observations on several important aspects of sewage purification:

In the first place, the fact that the majority of typhoid bacteria in sewage are bound to the solid particles is important from the hygienic standpoint. It is known that bacteria in such a state are fairly inaccessible to outer influences and this is confirmed here by the inaccessibility of the typhoid bacteria for the nutrient matter of the Wilson and Blair medium. It may reasonably be assumed that in their recesses the typhoid bacteria will be just as inaccessible to destructive influences and that inside the sludge particles their existence is, thus, pretty well assured. In the authors' opinion there is, in this instance, an analogy to be seen with the conservation of bacteria by drying bacteria-clumps (Otten 1930) and with many of our own experiences in the chlorinating of water containing solid matter in suspension. This conception gives a special, hygienic aspect to the mechanical purification of sewage by sedimentation. The decrease of 80 per cent in the typhoid bacteria occurring in the sewage while passing through the sedimentation-chamber, reported above, is important not only in a quantitative sense but also qualitatively inasmuch as it is just in the tank too, that the most dangerous, *i.e.* the "protected" typhoid bacteria are caught.

There is, moreover, still more to be noted. The figure of 80 per cent, just mentioned, must in reality be considerably higher since the typhoid-bacterial content of the tank influent is also higher than found in bacteriological examinations, as the sewage contained much more floating material before entering the tank than afterwards.

Further, it may reasonably be assumed that other intestinal parasites (dysentery- and paratyphoid bacteria, hookworms' eggs, etc.) together pass along the same way as the typhoid bacteria. It may, therefore, be expected that these too for the greater part disappear from sewage on mechanical purification.

For the practical application of sewage purification this is an indication that one may not underrate the technico-hygienic value of the sedimentation installation, because mechanical purification still allows many pathogenic organisms to escape, but that every good care given to the mechanical sedimentation in the purification of sewage is more than well repaid.

Behavior of Typhoid Bacteria During Digestion of Sludge

The settled sludge collects in the digestion-chamber and remains there until the methane fermentation is more or less complete.

Under our tropical conditions with an almost constant temperature of 27° C. this lasts about a month. The digested sludge drawn from the Imhoff tank is dried and afterwards transported, mostly into the country for the purpose of soil improvement (agri- and horticulture), and also for building up various grounds. In Europe and America

there are, evidently, no objections to this practice but in the tropics the uses of digested sludge are limited, due to the occurrence of great numbers of viable parasites, of which, as an especially dangerous example, the hookworm must be mentioned.

In contrast to European usage, care must be exercised with this sludge in tropical countries. In these circumstances its use on sports fields is quite undesirable.

What happens now to the typhoid bacteria in the sludge?

During the process of digestion they are in anaerobic surroundings in which they generally feel much at home while, moreover, they are protected against their classical enemies, the protozoa, which thrive badly in an anaerobic milieu. These circumstances cannot, therefore, be regarded as unfavorable to the typhoid bacteria.

The duration of the life period of typhoid bacteria in sludge was first investigated in the laboratory. With this object anaerobic sludge digestion was reconstructed in vitro as closely as possible resembling the Imhoff-tank conditions, by mixing fresh sludge with digested sludge and subsequently keeping this mixture in the dark at room temperature (an average of 23° C. at Bandoeng) in a vacuum desiccator with a solu-

TABLE XI.—*Disappearance of Typhoid Bacteria in Sludge under Anaerobic Conditions*

Experiments	Number of Days	Volume of Sludge Examined in c.c.	Total Number of Bacteria (W. & B. Agar) per c.c.	Number of Typhoid Strains Isolated	Number of Typhoid Bacteria per c.c.
1	0	0.01	4,100	0	—
	2	0.1	100	0	—
	3	1	30	11	11
	6	1	7	1	1
	10	1	8	0	—
2	0	0.01	52,800	0	—
	1	0.01	3,000	5	500
	2	0.01	500	2	200
	4	3	25	3	1
	5	7.5	4	0	—
	6	15	4	1	0.07
	7	15	2	0	—
	9	15	5	0	—
	11	15	1	0	—
	14	30	0.6	0	—
3	0	0.01	79,200	7	700
	1	0.06	2,400	28	470
	2	0.06	5,000	4	70
	3	1.5	10	0	—
	4	3	19	6	2
	5	2.5	7	5	2
	6	5	7	2	0.4
	7	15	4	0	—
	8	15	3	2	0.13
	9	30	2	0	—
	11	30	1	0	—

tion of pyrogallol and soda. This mixing of fresh with digested sludge was done to prevent acid fermentation. The pH of the sludge amounted to 7.1 and under these conditions, remained constant for the duration of the test.

The results of three experiments are given in Table XI.

The typhoid bacteria disappeared comparatively quickly; in one test they were found for the last time after 8 days, and in the other two tests after 6 days. The final point of the test could be easily determined because, as shown in the table, even the total number of organisms growing on the Wilson and Blair agar decreased markedly. There was, therefore, no indication that the growth of the typhoid bacteria on the plates was interfered with by these other organisms such as might well be the case in a test of fresh sludge.

Even with a very heavy artificial infection of typhoid bacteria, so that the number of them found at the commencement of the test was 116,000 per c.c., these had already disappeared from the sludge after 11 days.

The progress of this destruction is shown in the graph attached.

From these tests it would follow that the digestion-period of one month, which the sludge undergoes in the Imhoff tank, is amply sufficient to ensure the digested sludge being free of typhoid bacteria.

During the examination of digested sludge from the Imhoff tank, however, other results were obtained. These results for some samples are embodied in Table XII.

TABLE XII.—*Examination of Digested Sludge for Typhoid Bacteria*

Date of Taking Sample, 1939	Typhoid Bacteria per c.c.
March 8	0
March 14	22
April 1	2
April 14	2
May 8	0
May 17	0
June 6	2

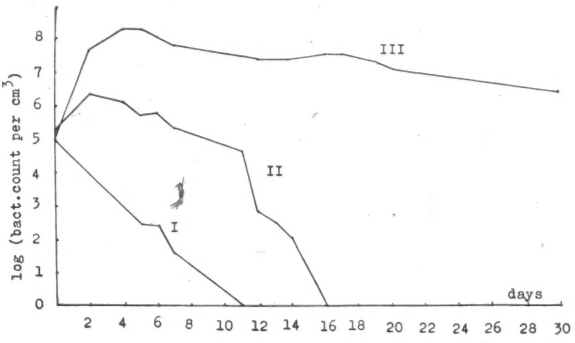
Thus in the majority of samples viable typhoid bacteria were found. During a control test of several of the strains isolated, made at the "Koningin Wilhelmina Instituut voor Hygiëne en Bacteriologie" at Batavia, it was shown by Dr. R. Gispen that these organisms still possessed Vi-antigen so that there was every reason to regard them as virulent bacteria.

The rapid disappearance of typhoid bacteria indicates that the laboratory conditions differ from those prevailing in the Imhoff tank. Important differences can immediately be pointed out. In contrast to the digestion-process in the laboratory test, mentioned above, the working of the Imhoff tank is continuous. The fresh sludge constantly settling in the digestion-chamber, collects in the top layers while the

digested sludge is drawn off from the bottom of the tank. During the process of digestion the sludge descends the chamber vertically to the bottom; the deeper it goes, the further digestion progresses. In consequence however of the abundant formation of gas during the digestion, a certain intermingling of the sludge layers takes place. Moreover, during the drawing off there will always be some sludge sucked down from the upper layers. The drawn off sludge will thus always be mixed more or less with fresher material.

It is for this reason that we shall always find very many bacteria growing in black colonies in digested sludge from the tank, but these have almost completely disappeared from sludge preserved in the laboratory for 2 to 3 weeks.

That comparatively small changes in the composition of sludge have an influence on the life of typhoid bacteria was shown in tests where typhoid bacteria were inoculated into sludge that had been pasteurized (10 minutes at 80° C.) or sterilized (30 minutes at 110° C.). Here it was found that typhoid bacteria throve considerably longer in sludge thus treated and in the beginning even multiplied (see Graph I). Al-



Survival of B.typhosum in Sludge from Imhoff-tank.

I = *B. typhosum* in untreated sludge.
II = *B. typhosum* in pasteurized sludge (10 min. 80° C.).
III = *B. typhosum* in sterilized sludge (30 min. 110° C.).

though the absence of antagonistic organisms may possibly be of some influence, it seems more probable that the organic matter, which by the heating is partly transformed into combinations more easily assimilated, favors the survival of typhoid bacteria.

That such material could also originate in an efficiently fermenting Imhoff tank through the influence of certain micro-organisms can very well be imagined, but in this case, competition between typhoid bacteria and saprophytes, also feeding on these materials, would be very vigorous and therefore it appears little probable that the biological conditions for the pathogenic organisms would thus be improved.

Whatever may be the explanation of this incongruity, in practice

account must be taken of the fact that this sludge does contain live typhoid bacteria when drawn from the tank.

At this point however, the treatment of the sludge is not yet completed. After leaving the Imhoff tank the sludge flows on to sand beds where it is dried. The loss of water through draining and evaporation and the aerobic surroundings undoubtedly have an unfavorable influence on the life of the typhoid bacteria. In confirmation of this no typhoid bacteria were found in 10 samples of thoroughly dried sludge. This negative result however must be accepted with the necessary reserve, having regard to the difficulties encountered in isolating typhoid bacteria from sludge and an extensive investigation into this matter is certainly needed. For the time being, the impression is given that typhoid bacteria, in contrast to some other parasites such as the hookworm, die off with suitable treatment of sludge.

Summary

During the examination of the sewage of Bandoeng for typhoid bacteria these were regularly found in numbers considerably higher than recorded in the data for Europe. This corresponds with the typhoid-morbidity which is very much lower in Europe than in Bandoeng, where this disease occurs endemically.

A comparative examination of sewage and surface-water proved that the concentration of typhoid bacteria is markedly higher in the sewage than in the river water, so that it may be assumed that in the areas that are sewered, the majority of the typhoid bacteria are intercepted by the sewer. In this connection, the importance may be stressed of a closed sewer in the combat of typhoid.

In the installation for sewage purification at Bandoeng, which consists of an Imhoff tank installation, the occurrence of typhoid bacteria was traced in the influent and the effluent of the tanks and also in the sludge.

During the passage through the Imhoff tank installation, approximately 80 per cent of the typhoid bacteria settle with the sludge. Although this purification is considerable, in most cases the effluent has still to be further dealt with.

In the isolation of typhoid bacteria from the Imhoff-tank influent and effluent and from the sludge, results were obtained which indicated a close connection between the solid sludge particles and the typhoid bacteria, in this sense that the sludge particles afford protection against outside influences to the typhoid bacteria they contain, and the more compact the structure of the sludge particles the greater the protection. The great technico-hygienic value of the sedimentation process in sewage purification is thus clearly demonstrated.

Investigations were made into the dying off of typhoid bacteria in sewage preserved in the laboratory and in sludge from the Imhoff tank.

Although the typhoid bacteria die off rather quickly in the sludge, they still could be found in the digested sludge from the Imhoff tank.

After drying the sludge, however, no further typhoid bacteria could be isolated.

References

Dinger, J. E. 1937. *Geneeskundig Tijdschrift voor Ned.-Indië*, **77**, 1090.

Holwerda, K. 1928. *Mededeelingen van den D. V. G. in Ned.-Indië*, **17**, 410.

Mom, C. P., en Schaafsma, N. D. R. 1933. *Mededeelingen van den D. V. G. in Ned.-Indië*, **22**, 161.

Mom, C. P., en Thijsse, J. P. 1935. Handelingen Decentralisatie-Congres Ned.-Indië.

Moses, H. E. 1936. *Journal of the American Waterworks Association*, **28**, 681.

Newman, G. 1932. Ref. in *Water and Water Engineering*, **35**, 595 (1933).

Otten, L. 1930. *Zentralblatt für Bakteriologie, Parasitenkunde und Infektionskrankheiten*, I Abteilung-Originale, **116**, 199.

Radsma, W. 1932. Diësrede Geneeskundige Hoogeschool Batavia.

Radsma, W. 1936. *Geneeskundig Tijdschrift voor Ned.-Indië*, **76**, 470.

Ruchhoft, C. C. 1934. *Sewage Works Journal*, **6**, 1054.

Rudolfs, W., and Gehm, H. W. 1937. *Sewage Works Journal*, **9**, 579.

Ruys, A. Ch. 1936. *Proc. Roy. Acad. Amsterdam*, **39**, 780.

Snuyf, S. 1937. *Ingenieur in Ned.-Indië*, **4**, (VI), 1.

Stewart, A. D., and Ghosal, S. C. 1932–33. *Indian Journ. of Med. Res.*, **20**, 341.

Walch, E. W. 1934. *Geneeskundig Tijdschrift voor Ned.-Indië*, **74**, 450, 514.

Wilson, W. J., and Mc V. Blair, E. M. 1927. *Journ. of Hyg.*, **26**, 374.

Wilson, W. J., and Mc V. Blair, E. M. 1931. *Journ. of Hyg.*, **31**, 138.

Winckel, Ch. W. F. 1927. *Geneeskundig Tijdschrift voor Ned.-Indië*, **67**, 579.

Plant Operation

TREATMENT OF SUPERNATANT SLUDGE LIQUOR BY COAGULATION AND SEDIMENTATION

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Numerous methods have been suggested and used to treat and dispose of supernatant sludge liquor. None of these has been satisfactory in every instance. With this thought in mind experiments were begun in the latter part of 1937 at the Baltimore sewage works to see if a considerable portion of the suspended solids in sludge liquor could be removed by sedimentation following coagulation. Subsequent to the completion of this investigation Rudolfs and Gehm (1) reported on the successful clarification of sludge liquor with lime, ferric chloride and other coagulants.

The purpose of the experiments was to determine the effect of the following variables on the clarification of sludge liquor:

I. Mixing coagulant and sludge liquor.
   A. Length of mixing period.
   B. Speed of mixer.

II. Flocculating sludge liquor.
   A. Length of flocculating period.
   B. Speed of flocculator.

III. pH adjustment.

IV. Quantity of coagulant used.

Method of Conducting Experiments

The sludge liquor was obtained from time to time from the two heated sludge-digestion tanks at the Baltimore sewage works, each of which has a capacity of approximately 200,000 cu. ft. Fresh sludge was removed every few hours from mechanically-cleaned preliminary sedimentation tanks and pumped into the digestors. The raw sludge was derived from sewage from a separate system of sewers. Analyses of each sample of sludge liquor are not given. The following gives the variation in these analyses:

	P.p.m.
5-day B.O.D. at 20° C.	790–1,700
Suspended solids	4,200–8,900
Turbidity	1,000–2,400
pH	7.0–7.6

The sludge liquor was mixed and coagulated in 1,000- and 2,000-c.c. beakers. A motor-driven, variable-speed gang mixer was used for mixing purposes. The pH value of the liquor was lowered by the addition of sulfuric acid. To raise the pH to any value up to 10.0 sodium carbonate was used, and to obtain a higher value sodium hydroxide was employed. After adjusting the pH value, a 10 per cent solution of ferric chloride was used for coagulating purposes. After the sewage solids had flocculated, the liquor was allowed to settle quiescently for 2 hr., and then the supernatant was drawn off and analyzed. The analyses consisted of determining the 5-day B.O.D., the suspended solids and the turbidity before and after treatment. In general only turbidities are reported as they are a good index to use in evaluating the results.

There were so many variables involved in treating the sludge liquor that it was necessary to study in turn the effect of each of these. The

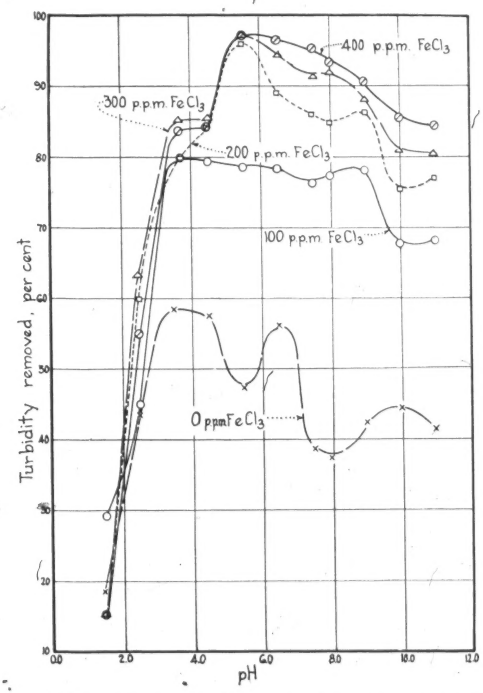


FIG. 1.—Removal of turbidity from sludge liquor at various pH values when treated with different amounts of $FeCl_3$. (Coagulant mixed for 1 min.; mixer speed—180 r.p.m.; flocculated for 30 min. at 60 r.p.m.; sedimentation period—2 hr.)

first step consisted of determining the effect of different pH values and different quantities of ferric chloride on the clarification of the sludge liquor. The pH value was varied from 1.5 to 11.0. Different amounts of ferric chloride up to 400 p.p.m. were used. With the mixer operating at 180 r.p.m. the ferric chloride and the sludge liquor were mixed for 1 minute, and then flocculated for 30 minutes with the mixer operating at 60 r.p.m. The best results were obtained (Fig. 1) when the pH of the sludge liquor was adjusted to about 5.5 or 6.0 and the dosage of ferric chloride was 400 p.p.m. At the optimum pH value 200 p.p.m. of the ferric chloride gave nearly as good results as 400 p.p.m. It is interesting to note that a considerable percentage of the turbidity was removed by flocculating and settling the sludge liquor when no ferric chloride was added. The best results were obtained when the pH value was approximately 3.5.

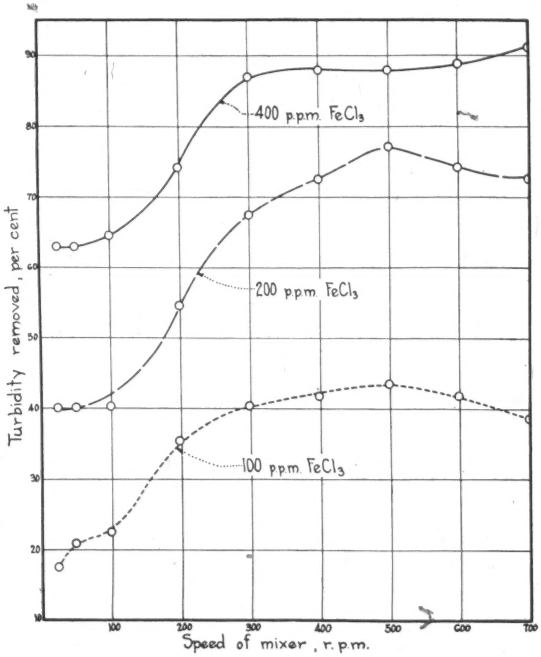


FIG. 2.—Effect of speed of mixer used to mix ferric chloride with sludge liquor on removal of turbidity. (pH not adjusted; mixing period —60 sec.; flocculation period—0 min.; sedimentation period—2 hr.)

Effect of Speed of Mixer.—The next step in the investigation was to determine if the speed of the mixer affected the results. The mixer speed was varied from 25 to 700 r.p.m., and from 100 to 400 p.p.m. of

ferric chloride was used. In each instance the mixing time was 60 seconds. The pH value of the sludge liquor was not adjusted and the material was not flocculated by stirring. In general the best results were obtained (Fig. 2) when the speed of the mixer was 400 r.p.m. or higher.

Effect of Flocculation.—The effect of flocculating the sludge liquor for various periods of time was then studied. The pH value of the liquor was adjusted to 5.5, the optimum value. A dosage of 200 p.p.m. of ferric chloride was then added and mixed for 10 seconds in one case, ½ minute in another and 1 minute in a third. The speed of the mixer was 500 and 800 r.p.m. At the termination of the mixing period the flocculation period was varied from 0 to 30 minutes with the flocculator operating at a speed of 60 r.p.m. Generally speaking, flocculating the sludge liquor (Fig. 3) had no beneficial effect.

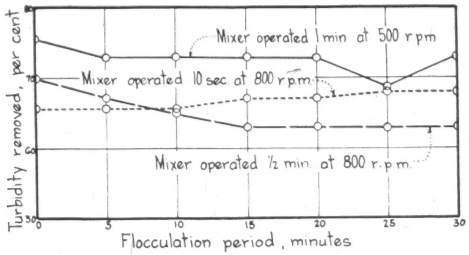


FIG. 3.—Effect of period of flocculation on turbidity removal from sludge liquor. (pH—5.5; $FeCl_3$ used—200 p.p.m.; speed of flocculator—60 r.p.m.; sedimentation period—2 hr.)

Effect of Mixing for Short Periods.—Mixing the ferric chloride and the sludge liquor for short periods from 5 to 60 seconds without subsequent flocculation was then investigated. The pH of the sludge liquor was adjusted to 5.5, and 200 p.p.m. of ferric chloride was added. The mixer was operated at speeds of 200, 400, 600, 800, 1,000 and 1,200 r.p.m. It was found that it was not necessary to operate the mixer (Fig. 4) for more than 10 seconds. Good results were obtained with speeds of 400, 600 and 800 r.p.m. When the speed was 600 r.p.m. or higher, prolonging the mixing period for more than 5 and at the most 10 seconds produced a poorer effluent.

Concluding Experiments.—The preceding experiments indicated that the coagulant should be rapidly mixed with the mixer operating at a speed of 600 to 800 r.p.m. for a short period of time (5 to 10 seconds) without subsequently flocculating the sludge liquor. In the concluding experiments the pH of the sludge liquor was adjusted from 2.0 to 11.0 and the dosage of ferric chloride was varied from 0 to 400 p.p.m. The analyses of the untreated sludge liquor were as follows:

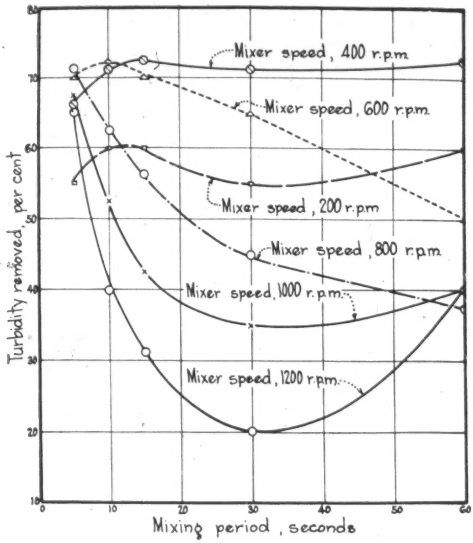


FIG. 4.—Effect of period of mixing coagulant with sludge liquor and speed of mixer on turbidity removal. (pH—5.5; $FeCl_3$ used—200 p.p.m.; flocculation period—0 min.; sedimentation period—2 hr.)

	P.p.m.
5-day B.O.D. at 20° C.	850
Suspended solids	4,460
Turbidity	1,200
pH value	7.3

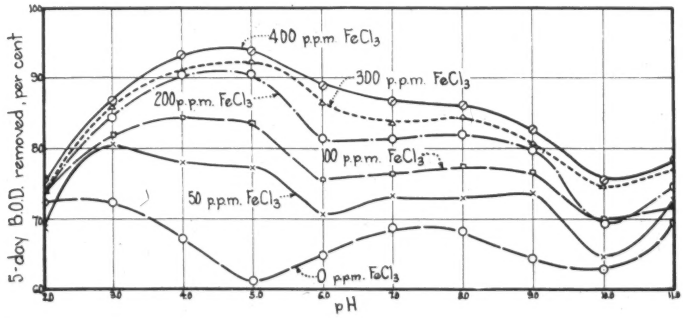


FIG. 5.—Removal of 5-day B.O.D. from sludge liquor when treated with various amounts of $FeCl_3$. (pH—2.0 to 11.0; coagulant mixed for 10 sec.; mixer speed—600 r.p.m.; sedimentation period—2 hr.)

The ferric chloride and the sludge were mixed for 10 seconds with the mixer operating at 600 r.p.m. The results of the treatment are shown in Figs. 5, 6 and 7. The greatest removal of B.O.D. was obtained at a

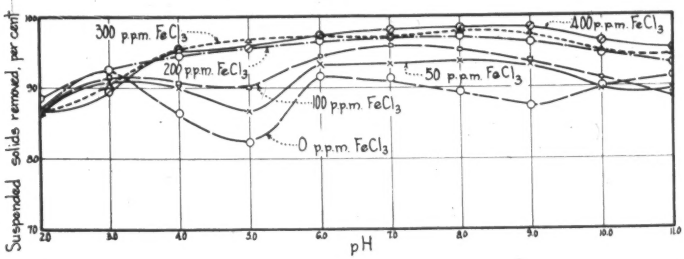


FIG. 6.—Removal of suspended solids from sludge liquor when treated with various amounts of $FeCl_3$. (pH—2.0 to 11.0; coagulant mixed for 10 sec.; mixer speed—600 r.p.m.; sedimentation period—2 hr.)

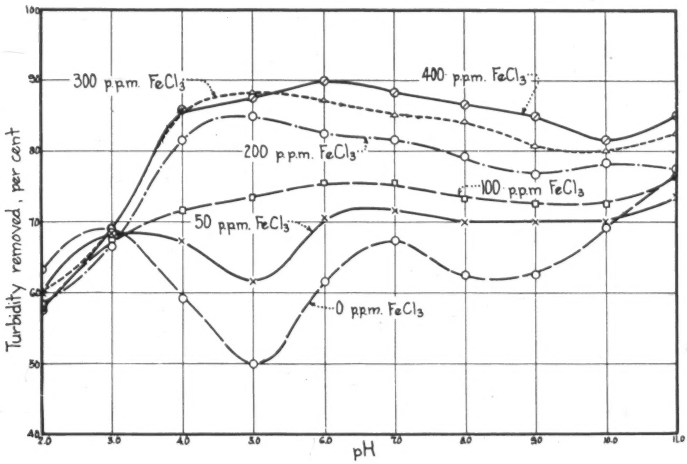


FIG. 7.—Removal of turbidity from sludge liquor when treated with various amounts of $FeCl_3$. (pH—2.0 to 11.0; coagulant mixed for 10 sec.; mixer speed—600 r.p.m.; sedimentation period—2 hr.)

pH value of 5.0 with 400 p.p.m. of ferric chloride. Using 300 p.p.m. gave nearly as good results. Over 95 per cent of the suspended solids (Fig. 6) was removed at any pH value between 5.0 and 9.0 by the use of 200, 300 or 400 p.p.m. of ferric chloride. The best results were obtained with 400 p.p.m. at a pH value of 9.0.

When no ferric chloride was used, the best results were obtained at pH values of approximately 3.0, 7.0 and 11.0. It should be noted that

the sludge liquor was mixed for 10 seconds with the mixer operating at 600 r.p.m. the same as during the other parallel group of tests when ferric chloride was used.

Conclusions

It seems justifiable to draw the following conclusions when using ferric chloride to coagulate sludge liquor:

1. Mixing the coagulant with the sludge for 5 to 10 seconds gave the best results.
2. Using a high-speed mixer operating at 600 to 800 r.p.m. is desirable.
3. The mixture of coagulant and sludge should flow immediately to a sedimentation tank without being flocculated.
4. The removal of B.O.D. was best at a pH value of 5.0.
5. A high removal of suspended solids was obtained at any pH value between 4.0 and 11.0.
6. Using 400 p.p.m. of ferric chloride gave the best results; however, using 300 p.p.m. was almost as satisfactory.

The sewage-treatment works is under the general supervision of George Cobb, chief engineer, Department of Public Works, and G. E. Finck, sewerage engineer, with G. K. Armeling, superintendent. J. W. Bushman, junior chemist, assisted in the laboratory work.

References

1. Willem Rudolfs and H. W. Gehm, "Supernatant Liquor Treatment with Chemicals," *This Journal*, 11, 19 (1939).

SEWAGE TREATMENT EXPERIMENTS CONDUCTED AT THE LOS ANGELES CITY PILOT PLANT *

By H. G. Smith and E. G. Studley

Engineer of Sewer Design and Supervisor of Plant Operation, City of Los Angeles, Cal.

In connection with a study of the betterment of the Los Angeles sewerage system, there has been more or less of a tacit understanding by all parties concerned that one of the essential corrections, regardless of differences of opinion relative to other improvements, was the junking of the existing screening installation at Hyperion and the construction, at that location, of a modern type of sewage treatment plant in order to eliminate the pollution of the bathing beaches on either side for several miles, and also to deodorize the atmosphere in the general vicinity.

It has been conceded, at least by the technically informed, that with Santa Monica Bay as a point of final disposal with its currents continuously bringing in millions of tons of clear salt water from the channel and thereby presenting an extremely large dilution and oxidation factor, any type of so-called complete treatment would be decidedly uneconomical and unnecessary.

Studies relative to design for a new plant were commenced by the Sewer Design Division of the Bureau of Engineering as early as 1934, at which time plain sedimentation and separate digestion were considered, the sludge to be dewatered on vacuum filters and the process continued in tubular dryers and incinerators with moving grates. Center feed clarifiers were just coming on the market and several types of flash dryers were being developed. The use of digester gas as an engine fuel was in its extreme infancy and flocculation without chemicals, or mechanical flocculation as we know it today, was not a proven factor in the treatment of sewage. Elutriation was still to make its general appearance and numberless gadgets and methods of control now common in many new plants had not been heard of.

Therefore our general design, to say nothing of detail, at that time was really a far cry from that of the plant now outlined and proposed.

With the expectation from year to year that either through pressure or conscience the city would decide to clean up its beaches, the Sewer Division has designed and redesigned, keeping abreast, at least on paper, with the new developments in treatment as experiments and installations were made from time to time by engineers fortunate enough to see their projects materialize. In fact the general flow chart of this plant is now known by its edition number rather than plan number, four editions having been prepared to date.

In 1927 extensive studies and experiments were made by Messrs. Knowlton and Parkes relative to the recovery of grease from Hyperion

* Presented at the Twelfth Annual Spring Conference of the California Sewage Works Association, Avalon, Santa Catalina Island, May 20–21, 1940.

sewage. While the experiments resulted in the development of a type of special grease recovery equipment which it is intended to adopt in the proposed new plant, due to lack of available funds no further experimental work was conducted until the summer of 1938, when the pilot plant now under discussion was placed in operation.

The purpose of this plant has been to simulate, on a model scale of practical dimensions, operations that might be conducted in a full size plant and thereby test different methods of clarification, digestion, elutriation and dehydration of sludge in several types of equipment, with various chemicals and without, and to study the reactions of this particular sewage through one year in order to acquire further data relative to the rational design of a flocculation-sedimentation, stage-digestion type of treatment plant.

Routine tests were conducted (in duplicate) daily in the plant laboratory while samples requiring special analysis and more complicated chemical apparatus were sent to the city's Bureau of Standards.

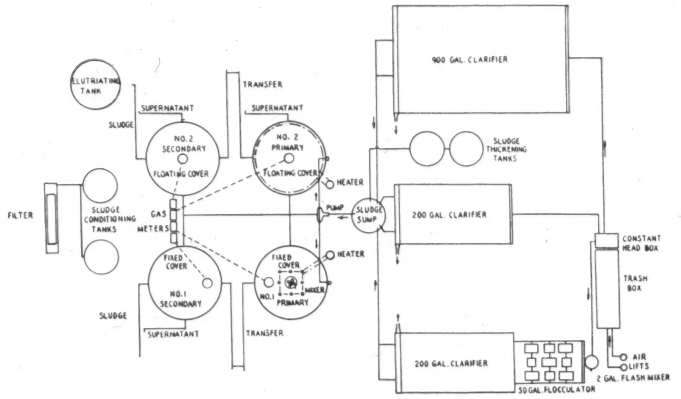


FIG. 1.—Diagram of experimental plant.

This experimental plant as outlined in Fig. 1 consisted of two clarifiers with a capacity of 200 gal. each and a third clarifier with a capacity of 900 gallons. The two smaller clarifiers were used for experimental clarification and the third clarifier was installed only to produce sludge for the experimental digesters.

A flocculator with a capacity of 50 gal., equipped with three sets of three paddles each, revolving at a speed of 11 r.p.m., was constructed adjacent to the upper end of one of the smaller clarifiers.

Thus with a flow of 2400 gal. per day to each of the smaller clarifiers 30 min. flocculation was obtained with 2 hr. retention in the clarifiers. The sewage was obtained from the Hyperion screening plant effluent by means of air lifts. This flow was first conducted through a trash

rack where the larger materials that passed around the screens were taken out so as not to obstruct the smaller openings throughout the system. The sewage then passed through a constant head box with controlled orifices for each clarifier so that a uniform rate of flow was always obtained.

The flow from the flocculator to the clarifier was under a separating baffle, as there was no inlet weir in the latter tank. The clarifier effluent passed over a weir the full width of the tank.

Once or twice each day the clarifiers were squeegeed by hand, the sludge drawn off through separate cocks and pumped to sludge storage barrels for thickening by decantation.

When chemicals were used, they were fed with the influent to the bottom of a flash mixer with 75 sec. retention, from which the influent overflowed to the flocculator.

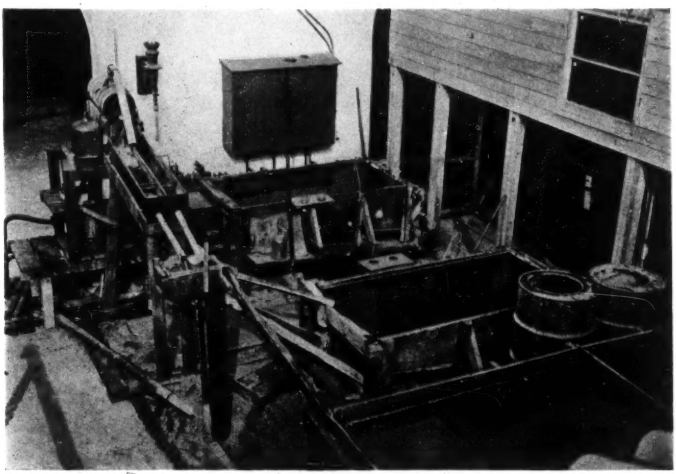


ILLUSTRATION 1.—Air lift, trash rack, constant-head box, chemical solution bottle, flash mixer, flocculator, two small clarifiers and one large, and sludge thickening barrels.

A second flocculator was installed ahead of the other small clarifier during the two-stage clarification experiments. For one hour retention, false sides and an end were placed in one of the clarifiers so as not to reduce the retention period in the flocculator.

In order to determine the effectiveness of clarification under all conditions, samples were taken from 8 A.M. to 4:30 P.M. every 15 min. and the composite samples analyzed for suspended solids. Settleable solids were also obtained from grab samples each morning and afternoon.

At the same time there were installed two sets of two-stage digestion tanks. Both sets consisted of a 470 gal. primary and 470 gal. secondary tank.

The No. 1 set of tanks had fixed covers, the primary containing a central heating coil and central stirring mechanism. The secondary was neither stirred nor heated.

The No. 2 set of tanks had floating covers on both primary and secondary. The primary was heated with a peripheral heating coil and

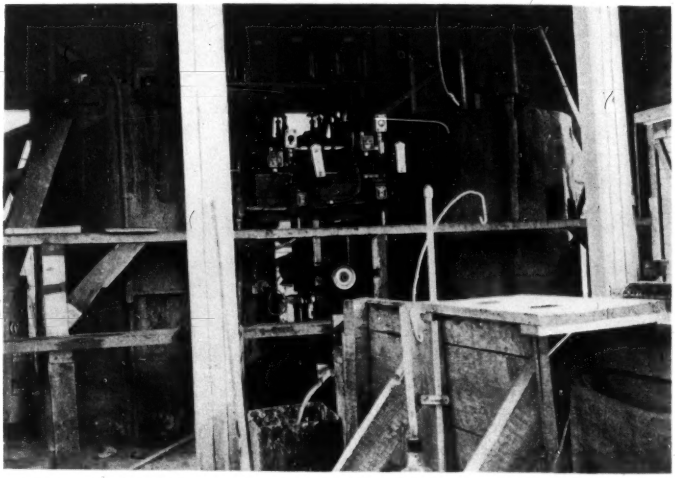


ILLUSTRATION 2.—Primary digesters with circulating pumps and temperature controls, sludge measuring buckets, and gas meters.

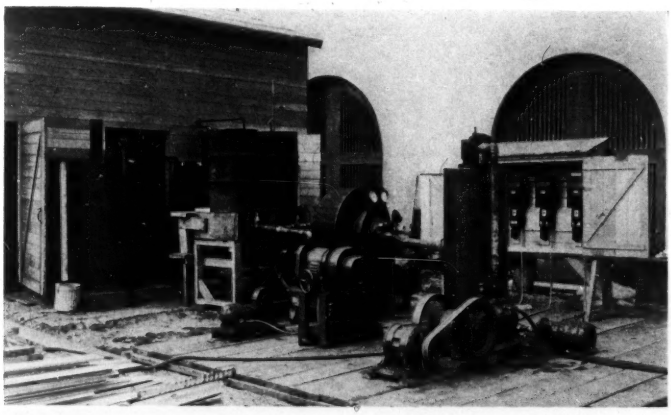


ILLUSTRATION 3.—Secondary digesters, sludge conditioning barrels, and vacuum filter with variable speed drive, filtrate receiver, vacuum pump and electrical controls.

was not stirred. The secondary of this No. 2 system was also unheated and unstirred.

Gas was collected in domes on the covers of all tanks and piped to separate gas meters, one meter for each tank.

Means were provided for transferring sludge from both primary tanks to their secondary tanks from which secondary supernatant liquor could be drawn off at any level or sludge removed from the bottom. The No. 2 primary tank, which was not stirred, was also equipped with a supernatant draw-off pipe which was adjustable so the supernatant could be removed from any elevation.

Both the clarifiers and the digesters were operated simultaneously and the laboratory work carried on at the same time, but in order not to confuse the results they will be presented herewith separately.

Discussion of Results

The results obtained from the operation of this experimental plant indicated that the theoretical data originally adopted in the proposed Hyperion plant design were too liberal with regard to several of the units and therefore the comparatively small cost of operating this plant over the 20-months period it was in service will result in a saving of at least several hundred thousand dollars in the construction of the new Hyperion plant and the design may be accomplished with a considerably greater degree of confidence than would otherwise have been the case.

The Hyperion sewage is well adapted to physical and chemical flocculation prior to sedimentation and one hour detention in the clarifier is ample.

The Hyperion sludge is satisfactorily digested in two-stage digesters with continuous sludge mixing in the primary stage with either mesophilic or thermophilic digestion with loadings as follows:

Type of Digestion	Temp.	Pounds of Dry Solids per Cu. Ft. of Primary Digester Capacity per Month
Mesophilic	85° F.	12
Thermophilic	130° F.	22

Elutriation, at least in connection with mesophilic digested sludge, indicated a very appreciable saving in chemicals in conditioning the sludge for filtering and is deemed essential for Hyperion sludge.

By the use of elutriation the following yields are anticipated, with the indicated percentage of $FeCl_3$, from vacuum filters:

2.5% $FeCl_3$—1.65 pounds dry solids per sq. ft. per hour
5.5% $FeCl_3$—5.95 pounds dry solids per sq. ft. per hour

Clarification

Clarification was started July 20, 1938.

NOTE:- Unless Otherwise Indicated All Points Are Plotted From Averages Of From 4 To 9 Days Of Experimental Work Which Was Performed During The Hours Of 8 A.M. To 4:30 P.M.

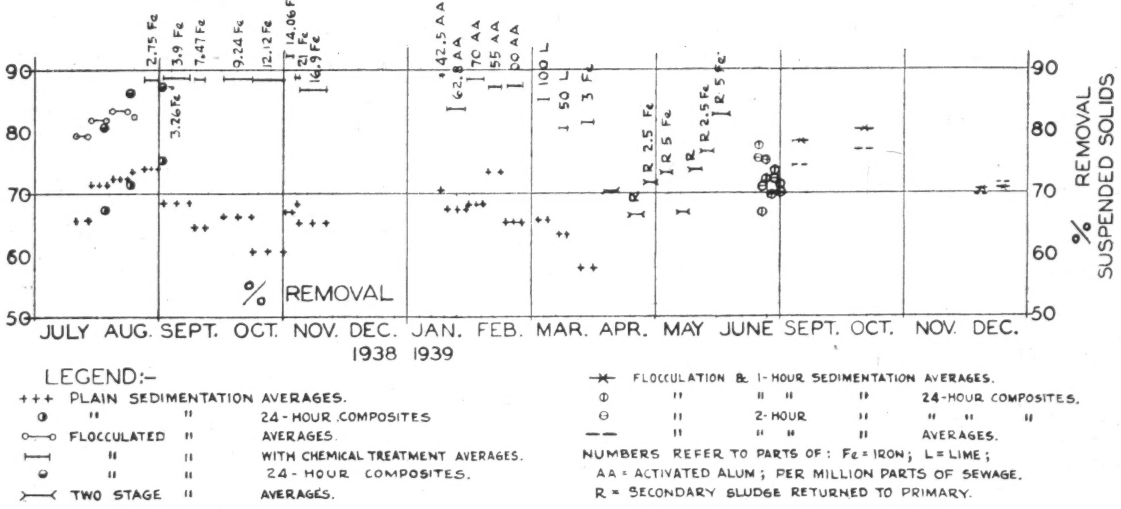


FIG. 2.—Experimental sedimentation with flocculation and chemical treatment at Hyperion 1938–1939.

The indicated percentages of removal (Fig. 2) apply to the reduction in amount of suspended solids determined from duplicate samples taken from the composite of the influent and effluents of the clarifiers every 15 min. from 8 A.M. to 4:30 P.M. "Standard Methods" was not followed for determining suspended solids but rather the aluminum cup method using Celite wherein the filtered quantity was 1 liter.

Twenty-one different conditions of clarification were tried for not less than five days. The averages for each condition were as follows:

No. of Days	Condition	Suspended Solids		
		Parts per Million		Per Cent Removal
		Influent	Effluent	
101	Plain sedimentation—2 hr. ret.	286	91.0	68.2
51	30 min. flocculation—2 hr. sediment	275	63.8	76.8
30	30 min. flocculation—1 hr. sediment	263	66.7	74.7
17	30 min. flocculation—2 hr. sed. 3 p.p.m. $FeCl_3$	319	43.7	86.3
7	30 min. flocculation—2 hr. sed. 4 p.p.m. $FeCl_3$	328	37.6	88.5
6	30 min. flocculation—2 hr. sed. 7 p.p.m. $FeCl_3$	297	34.6	88.3
10	30 min. flocculation—9 p.p.m. $FeCl_3$ 2 hr. sed.	300	33.6	88.8
7	30 min. flocculation—2 hr. sed. 54 p.p.m. Act. Alum	336	42.4	87.4
7	30 min. flocculation—2 hr. sed. 63 p.p.m. Act. Alum	258	41.6	83.8
6	30 min. flocculation—2 hr. sed. 70 p.p.m. Act. Alum	212	24.6	88.4
7	30 min. flocculation—2 hr. sed. 100 p.p.m. Act. Alum	254	32.0	87.4
5	30 min. flocculation—2 hr. sed. 50 p.p.m. Lime	265	52.3	80.3
5	30 min. flocculation—2 hr. sed. 100 p.p.m. Lime	281	41.5	85.2
Two-stage—no primary flocculation: 50 min. retention in each clarifier—12½ min. in sec. flocculator				
6	No sludge returned	236	70.0	70.3
6	Secondary sludge returned	251	83.0	66.9
6	2.59 p.p.m. $FeCl_3$ added to sec. floc-sec. sludge returned	250	71.0	71.7
5	5 p.p.m. $FeCl_3$ added to sec. floc-sec. sludge returned	265	67.6	74.5
Two-stage with primary and secondary flocculation: 50 min. retention in each clarifier and 12½ min. in each flocculator				
6	No sludge returned	238	79.5	66.6
6	Secondary sludge returned	267	70.0	73.8
6	2.5 p.p.m. $FeCl_3$ added to sec.-sec. sludge returned	251	59.3	76.4
6	5 p.p.m. $FeCl_3$ added to sec.-sec. sludge returned	207	35.7	82.7

Figure 3 shows these averages graphically.

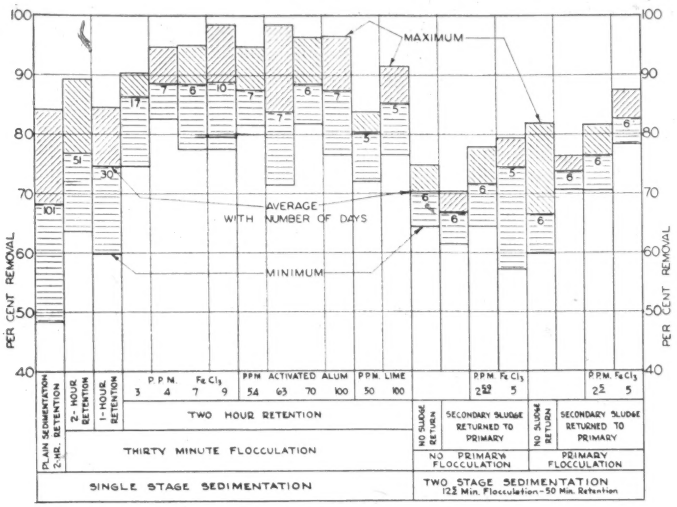


FIG. 3.—Results of settling tests, suspended solids.

In order to correlate the results obtained during the day with results that would have been obtained on a 24 hr. basis samples were taken for nine days on a 24 hr. basis. The average percentages of removals were as follows:

8 A.M. to 4 P.M.	Floc.—2 hr. clarif..... 74.9	Floc.—1 hr. clarif..... 77.2
24 hr. Ave.	Floc.—2 hr. clarif..... 72.8	Floc.—1 hr. clarif..... 72.4

Attention is called to the results obtained from 30 min. flocculation and 2 hr. clarification which have been averaged for 51 days. Between July 20 and Aug. 19, 1938, there were 20 days and between Sept. 6 and Dec. 21, 1939, there were 31 days. The average results from these two periods are very interesting.

	Influent	Effluent	Per Cent Removal
20 days Summer, 1938.....	293.0	54.9	81.3
31 days Winter, 1939.....	263.5	70.9	73.1

Therefore in the summer, with the strongest sewage, the effluent was actually better than it was in the winter with weaker sewage.

DIGESTION

The two sets of two-stage digestion tanks are identical in size and were loaded with identical sludges. The same temperature was main-

tained in the primary of each. In No. 1 primary there was a central stirring mechanism so that the contents of the tank were uniform throughout. On making additions to this primary, the overflow to the secondary was automatic and represented the contents of the tank. In No. 2 primary there was no stirring and it was necessary to withdraw supernatant liquor from the tank as long as it was reasonably clear because if the transfer was made automatically from the bottom to the secondary, the primary was soon depleted of seed sludge. No experiments were made where seed sludge was added to the primary with the raw sludge.

The No. 2 tanks had floating covers, the No. 1 tanks fixed covers. This reduced the capacity of the former slightly below that of the latter.

The tanks were seeded with sludge from Terminal Island in July, 1938, and the primaries operated at 85° F.

The quantity added daily was measured in 4-gal. buckets. All sludges and supernatant liquors were sampled and run for moisture, volatile and ash. The daily gas production from each tank was measured in standard gas meters.

The loadings on the digesters were increased from time to time in order to determine the maximum loadings with accompanying gas production and decrease in volatiles.

Table I gives the monthly loadings and results for both sets of digesters.

In the No. 2 digester (without mixing) foaming developed in January 1939. This tank was rested and the loading decreased before further increases. In April, 1939, it again foamed and again in June, 1939.

Figure 4 shows, on half-month averages, the loading in lb. of dry solids per cu. ft. of primary digester capacity per month, the quantity of gas produced per cu. ft. of dry solids added to the digester, and the percentage of reduction in volatiles.

The No. 1 digester, with mixing, was operated at 85° F. until Aug., 1939, when foaming developed. From Nov., 1939, to Feb., 1940, this digester was operated under thermophilic conditions at 130° F. No foaming occurred at any time at this temperature even with a retention period of 2¾ days in the primary, although at this loading there was not sufficient digestion in the primary so that too much of a load was imposed on the secondary.

Figure 5 shows the half-month averages of loadings in lb. of dry solids per cu. ft. per month, cu. ft. of gas per lb. of dry solids added, and percentage reduction in volatiles.

The sludge produced at the maximum loadings drained and dried satisfactorily on sand beds and could be filtered in the laboratory using Genter's Buchner funnel method (1) or a .10 of a sq. ft. cylindrical filter. The sludge had only a very slight sewage odor.

From these experiments we believe it is safe to use the following loadings when the primary digester has mixing:

Mesophilic digestion at 85° F.; 12 lb./cu. ft./mo., with not less than 55 per cent reduction in volatiles; 7 cu. ft. of gas per lb. of dry solids.

TABLE I.—*Recapitulation of Two Stage Digestion Experiments at Hyperion*

Date	Digester System No. 1 (With Mixing)			Cap. Primary 62.26 Cu. Ft.		Digester System No. 2 (Without Mixing)			Cap. Primary 59.29 Cu. Ft.	
	Lbs. Dry Solids Added	% Volatiles	% Reduction	Total Cu. Ft. Gas Prod.	Loading in Lbs. of Dry Solids per Cu. Ft. per Mo. (Based on ½ Mo. Average)	Lbs. Dry Solids Added	% Volatiles	% Reduction	Total Cu. Ft. Gas Prod.	Loading in Lbs. of Dry Solids per Cu. Ft. per Mo. (Based on ½ Mo. Average)
Mesophilic Digestion at 85° F.										
1938										
July 22 to 31	109.16	59.64		35	5.53	130.53	57.84			6.70
Aug. 1 to 15	15.99	76.8		205	.52	15.99	76.8		200	.55
Aug. 16 to 31	72.88	75.8		505	2.22	72.88	75.8		220	2.34
Sept. 1 to 15	85.12	68.3		650	2.77	85.13	68.3		170	2.90
Sept. 16 to 30	89.34	71.8		775	2.91	89.34	71.8		450	3.05
Oct. 1 to 15	93.99	73.1		750	3.05	93.99	73.1		405	3.21
Oct. 16 to 31	54.44	75.8		630	1.69	55.44	75.8		290	1.77
Nov. 1 to 15	108.24	76.5		765	3.53	108.24	76.5		450	3.71
Nov. 16 to 30	90.96	76.5	65.2	795	2.96	90.94	76.5	60.4	445	3.11
Dec. 1 to 15	112.78	76.7	63.2	880	3.67	112.88	76.8	57.9	555	3.86
Dec. 16 to 31	91.03	72.3	55.0	735	2.78	89.74	71.90	48.5	545	2.88
1939										
Jan. 1 to 15	169.38	75.6	58.3	995	5.52	135.57	75.2	54.4	525	4.63
Jan. 16 to 31	182.53	74.7	60.0	1700	5.57	5.07	77.7		1570	0.16
Feb. 1 to 14	164.73	75.5	61.4	1570	5.75	86.12	75.4	60.6	1080	3.15
Feb. 15 to 28	148.48	73.7	53.7	1290	5.17	98.53	73.8	58.8	775	3.61
Mar. 1 to 15	189.43	76.2	61.3	1425	6.17	145.26	76.7	62.8	750	4.96
Mar. 16 to 31	217.31	78.3	61.9	1700	7.07	155.99	78.3	66.9	570	5.33
Apr. 1 to 15	223.58	77.8	61.0	1860	7.28	144.84	77.8	64.9	505	4.95
Apr. 16 to 30	242.20	77.2	59.8	1660	7.90	54.96	77.2	64.8	1255	1.88
May 1 to 15	255.03	77.0	55.3	1910	8.31	135.19	76.8		1140	4.62
May 16 to 31	244.33	78.0	63.1	2065	7.47	203.56	78.2	61.5	1215	6.96
June 1 to 15	289.81	77.7	55.7	2240	9.45	132.34	77.45	57.4	1160	4.53
June 16 to 30	352.11	77.6	56.7	2465	11.46					
July 1 to 15	292.46	77.8	57.2	2315	9.54					
July 16 to 31	453.39	78.0	58.3	3040	13.83					
Aug. 1 to 15	482.58	78.9	59.1	3130	15.70					
Aug. 15 to 22	211.81	77.8	52.4	1445	14.80					
Thermophilic Digestion at 130° F. Cap. Prim. Reduced to 55.98 Cu. Ft.										
Oct. 5 to 15	315.80	79.90	69.0	610	17.10					
Oct. 16 to 31	180.10	80.00	58.0	690	6.10					
Nov. 1 to 15	158.78	78.50	60.2	790	5.75					
Nov. 16 to 30	384.65	79.80	57.2	2360	13.94					
Dec. 1 to 15	450.44	80.20	54.6	3448	16.30					
Dec. 16 to 31	574.50	79.40	53.5	3930	19.50					
1940										
Jan. 1 to 15	786.52	75.80	43.8	4215	28.50					
Jan. 16 to 31	982.97	75.50	43.8	4715	33.40					
Feb. 1 to 15	1051.18	72.64	45.8	4635	38.10					

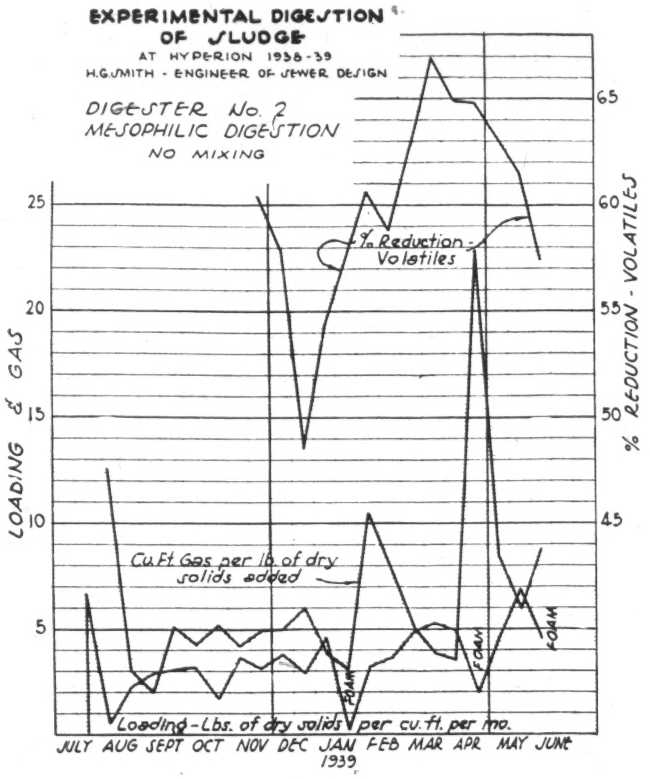


FIG. 4.

Thermophilic digestion at 130° F.; 22 lb./cu. ft./mo., with 50 per cent reduction in volatiles; 6 cu. ft. of gas per lb. of dry solids.

FILTRATION AND ELUTRIATION

On November 22, 1938, we received from the Oliver Filter Corporation in Oakland the equipment necessary to install and operate a vacuum filter of 3 ft. diameter by 1 ft. wide. This equipment was installed on a wooden platform adjacent to the experimental plant and consisted of an agitator drive, a variable speed drum drive, a filtrate receiver, a vacuum pump and electric control panel, in addition to the filter unit.

The digested sludge from the secondary digesters was placed in conditioning barrels where various percentages of ferric chloride and lime, or ferric chloride alone, were added, based on the amount of dry ma-

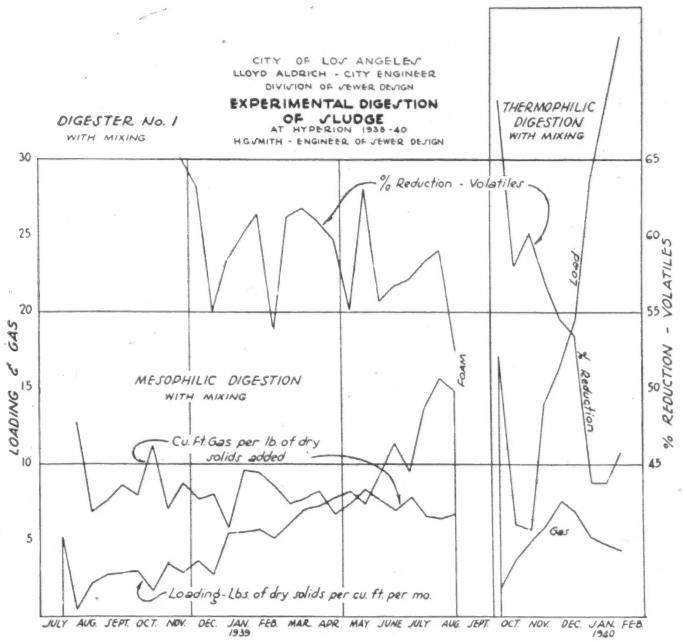


FIG. 5.

terial in the sludge. With these varying percentages of conditioning chemicals, various operating conditions of the filter were used to determine the quantity of dry solids which would be produced per hour per sq. ft. of filter area.

Between December 9, 1938, and February 24, 1939, 29 experimental runs were made with sludge as it came from the digesters either with or without decanting off free water.

Between February 24, 1939, and March 20, 1939, a larger tank with draw-off cocks spaced on the outside and equipped with a picket fence thickener was installed for the elutriation of the digested sludge prior to its conditioning for filtering. The elutriation consists of washing the sludge with several volumes of effluent or tap water in order to remove by dilution the ammonia compounds present in the sludge, that increase the amount of conditioning chemicals required for filtering.

From March 20, 1939 to June 26, 1939, 57 runs were made on elutriated sludges and 14 runs on identical sludges without elutriation, with various percentages of conditioning chemicals and various operating conditions of the filter. Various ratios of wash water were also used.

For each of these runs a laboratory analysis was made to determine the percentage of moisture of the digested sludge to be filtered and of the filter cake as it came from the filter. Many determinations were also made of the quantity of suspended solids in the filtrate.

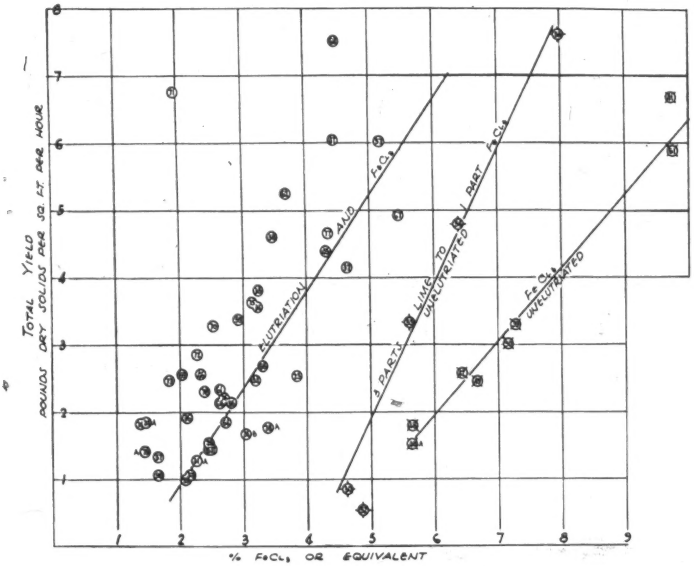

TOTAL YIELD
POUNDS DRY SOLIDS PER SQ. FT. PER HOUR
% FeCl₃ OR EQUIVALENT
ELUTRIATION AND FeCl₃
¼ PART LIME TO UNELUTRIATED FeCl₃
¼ PART LIME TO UNELUTRIATED FeCl₃

FIG. 6.—Comparison of filter yields using $FeCl_3$ with and without lime on unelutriated sludge, and $FeCl_3$ on elutriated sludge.

Figure 6 shows the yield in lb. of dry solids per sq. ft. per hour for each filter run made between March 20 and June 21, 1939, for the varying percentages of equivalent $FeCl_3$. Equivalent $FeCl_3$ is used because without elutriation better results were obtained using lime with $FeCl_3$, and this lime is included in this tabulation as equivalent $FeCl_3$ based on cost of the two materials. In the yield, however, where lime was used, the weight of the $CaCO_3$ which was precipitated by the addition of the lime was deducted from the indicated yield in order to be on the same basis as the other runs.

The filter runs made between Dec. 9 and Feb. 24 are not shown because the results were so variable as to indicate the presence of large percentages of dead seed sludge.

For Hyperion sludge, elutriation is deemed essential in connection with sludge conditioning and the following yields are anticipated, with the indicated percentage of $FeCl_3$:

2.5% $FeCl_3$ ..... 1.65 lb. dry solids per sq. ft. per hour
5.5% $FeCl_3$ ..... 5.95 lb. dry solids per sq. ft. per hour

Acknowledgment

This experimental work was done under the jurisdiction of the Board of Public Works of the City of Los Angeles, Lloyd Aldrich, City Engineer; and under the direct supervision of H. G. Smith, Engineer of Sewer and Plant Design and Operation, with E. G. Studley, Supervisor, in charge of operations at the plant.

References

1. A. L. Genter, "Adsorption and Flocculation as Applied to Sewage Sludges," This Journal, 6, 4 (July, 1934).

A YEAR'S EXPERIENCE IN DIGESTION OF SEWAGE AND GARBAGE SOLIDS *

By George F. Wyllie

Supt., Sewage Treatment Plant, Lansing, Michigan

Before entering any discussion of operating results on the digestion of sewage and garbage solids it might be well to give a brief description of the Lansing Sewage and Garbage Treatment Plant insofar as the handling of garbage and sludge digestion and disposal are concerned.

A unique system of garbage collection has been developed here in Lansing. Garbage is collected in cans furnished by the City. A charge of $1.50 per year is made for each can furnished and for this small charge each customer receives each week a freshly washed, clean garbage container. During July, August and September collections are made twice weekly. Collection is by platform trucks rather than dump trucks and normally five trucks are used in this service. During the double collection period in the summer nine trucks are used.

The collecting trucks deliver the loaded cans to the Treatment Plant where the cans are unloaded on a receiving platform. The cans are dumped by hand on the platform and paper, large boxes, tin cans, silverware and other trash which finds its way into garbage is sorted out by hand. The garbage is pushed down a chute directly into the garbage grinders which are mounted on a mezzanine floor just below the receiving floor. The cans are placed on a conveyor and carried through a can washing machine where they receive a thorough washing with hot water. The washed cans are stacked at the opposite end of the receiving dock and are picked up by the collecting trucks on their way out from the plant.

There are two garbage grinders, each rated at six tons per hour of green garbage. These grinders are of the hammer mill type manufactured by the Jeffrey Manufacturing Company. Some water is added during the grinding to facilitate the grinding and also to aid in moving the ground garbage through pipe lines. The ground garbage drops from the grinders into ejectors mounted directly below the grinders. These ejectors are each of 200 gallons capacity, and are manually controlled from the receiving platform. A signal system indicates to the operators when the ejector is full or empty. The ejectors discharge directly into the 8-inch raw sludge line leading to the digesters. This line is approximately 150 ft. long and discharges at a level some 18 ft. above the ejector outlets.

There are four digestion tanks of the fixed cover type equipped with scraper mechanism and scum breakers. Each tank is 60 ft. in diameter and 26 ft. deep at the sidewall and the combined capacity is 300,000

* Presented at the Ffteenth Annual Conference of the Michigan Sewage Works Association, East Lansing, May 9, 1940.

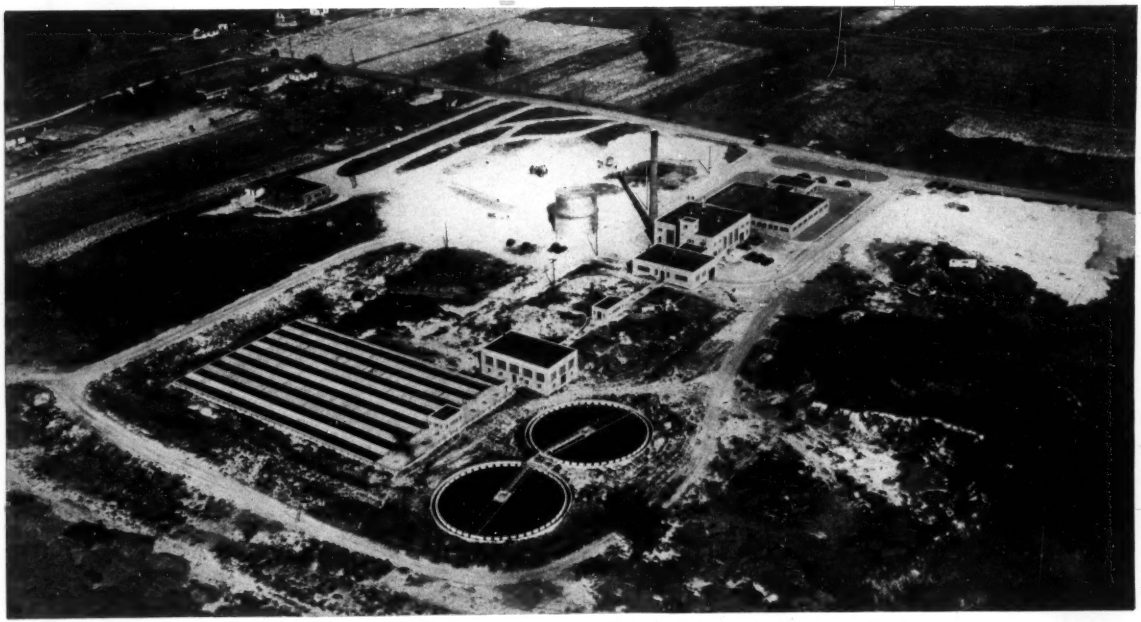


FIG. 1.—The Lansing, Michigan, Sewage Treatment Works (Abrams Aerial Survey Corp.).

cu. ft. The design of the digesters is based upon 3 cu. ft. per capita for a population of 100,000. A small gas collection dome is provided on each digester and a 25,000 cu. ft. capacity gas holder floats on the gas collecting system. The digestion tanks are heated by the cooling water from a 240 HP. gas engine. Sludge is added at the top and means are provided for venting any air that might be mixed with the garbage due to improper operation of the garbage ejectors. Digested sludge is drawn from the bottom of the tanks.

Sewage is given complete treatment by the activated sludge process using diffused air for aeration. The design of the plant is based upon a flow of 9.0 M.G.D. from a population of 100,000. The present connected population is estimated at 75,000. The sewage flow has been higher than was anticipated in design and during the past year the flow averaged 8.12 M.G.D. and during the last six months the flow was 8.47 M.G.D. or nearly 94 per cent of the design capacity of the plant. Digested sludge is partially dewatered on a vacuum filter and either burned or dried in an incinerator of the multiple-hearth type.

The sewage treatment plant was placed in full operation in September, 1938, and it was expected that no garbage would be handled until the following July. The agreement between the City of Lansing and a farmers' cooperative piggery at Williamston expired at that time and it was felt that that period would be sufficient to get the sewage treatment processes functioning smoothly. It was also planned to deliver small amounts of garbage to the treatment plant from time to time and get the garbage handling equipment thoroughly tried out and adjusted before attempting to handle the total garbage load. This program received a severe jolt when the piggery was suddenly closed at the end of February and since February 28, 1939, we have been handling all the garbage from the City of Lansing without interruption. The Garbage Department had not completed the installation of the can washing equipment and it was necessary to deliver the garbage in the dump trucks which had formerly delivered the garbage to the piggery.

In the building of the plant the costs of certain items had to be kept within the limits set up in the P.W.A. grant to the City and among the items omitted was the scale for weighing garbage received at the plant. I mention this so that figures given later on weights of garbage handled will not be accepted as necessarily accurate. They are rather a more or less intelligent estimate based upon weights of garbage obtained during the period garbage was being delivered in dump trucks, correlated to the number of ejections to the digesters during the same period. After the collecting trucks began delivering garbage direct to the Treatment Plant it was impossible to get accurate weights since the trucks did not pass any common set of scales. We have purchased a set of truck scales and expect to have more reliable data to offer next year on weights of garbage handled. However, we estimate that during the past year daily collection of garbage has averaged close to 21 tons per day with peak loads during September of 32 tons per day. This is about 0.55 pounds per day of green garbage per capita, which is

about the average figure in the United States. The ground garbage averages about 90 per cent water, including the water added during grinding, and the volatile content has been close to 93 per cent. Occasional tests for grease content show a figure of about 20 per cent (dry basis).

Several minor problems have arisen in handling garbage as outlined herein. It was found by experience that the ground garbage could be handled through the pipe lines much more readily if we pumped raw sludge at the same time. The raw sludge appears to dilute the ground garbage and enables the grinder men to operate the ejectors with air

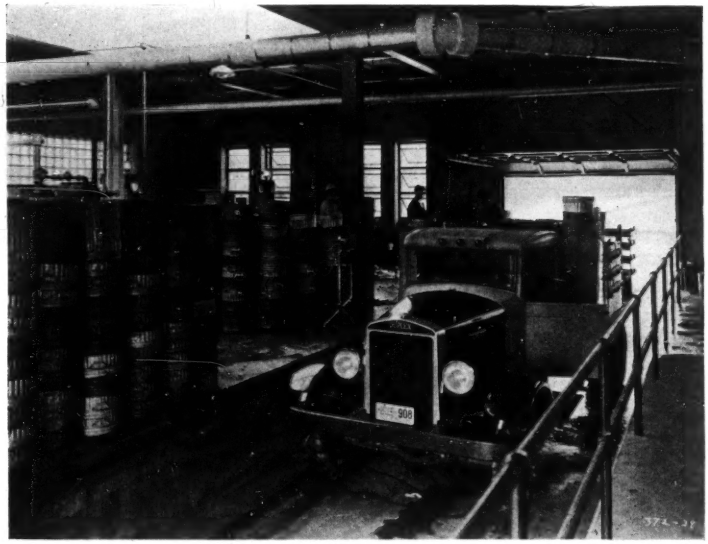


FIG. 2.—Collecting truck unloading garbage cans at receiving dock.

pressures of 25 lb. per sq. in. or less. The continuous flow of sludge also serves to keep the line flushed clean of garbage during the periods the grinders are idle. So far we have had no trouble due to clogging of the raw sludge line due to garbage.

The vents provided on the digesters did not prove entirely satisfactory and at first considerable garbage and sludge was spewed out on the digester roofs. An 8-in. tee was provided where the sludge pipe dropped through the roof of the digester and a 3-in. riser with a turned down elbow served as a vent. We have substituted 55-gal. oil drums for the 3-in. vents with fairly good results. The drums act more as surge chambers than vents as the rate of discharge through the sludge

line is 3 or 4 times greater than normal during the period of ejector discharge. Some skill in handling the ejector controls is required and with careless operation it is possible to blow considerable sludge from the vents. This is especially true at the end of the day's grinding when the receiving platforms are thoroughly washed down and the ejector contents are mainly water. The same pressure on the ejector will empty it much faster than when it contains the heavier ground garbage.

The water seals on the collecting domes on the digesters were constructed to provide a seal of 14 inches. The surges caused by too rapid ejection of garbage solids, coupled with high rate of gas production, would cause the seal to overflow and eventually the water would be blown entirely from the seal, resulting in the loss of considerable gas if not discovered immediately and also in damage to the gas meters due to higher speed operation than they were designed for. The trouble was finally overcome by constructing an extension around the gas dome that serves to catch any water blown from the seal and return it to the seal. This arrangement serves as an automatic pressure relief valve and prevents building up excessive pressures in the digesters. We ordinarily operate with about 11 in. water pressure in the digesters.

A more serious problem and one that still confronts us is the matter of bones and eggshells in the garbage. When we started handling garbage we attempted to remove only what would ordinarily be termed trash. Bones were delivered to the grinders and were ground without any difficulty and no further attention was given them. However, after about 7 weeks of garbage handling we began to experience trouble with the clogging of the digested sludge lines. This clogging was due principally to bones and eggshells aided and abetted by bottle caps. The lag in development of this trouble is explained by the fact that the plows on the sludge removal equipment in the digester clear the tank bottoms by about 1 in. and this amounts to some 33 cu. yd. storage or about 21 cu. ft. per day storage from the time grinding operations were started. This figure checks well with our later experience in flushing sludge lines. The garbage handling crew now attempt to sort out the bones and we derive an income of some $30 a month from the sale of bones to a rendering company. This represents the sale of about 2 tons of bones. However, there are still plenty of bones which get through to the digesters. Eggshells are as big a source of trouble as the bones and in fact, are more troublesome in that a line plugged mainly with eggshells is more difficult to open. I might state here that this trouble is not due to the failure of the grinders to properly grind the bones or eggshells but to the specific gravity of the material which causes it to settle out rapidly in the digested sludge. No trouble is experienced in the raw sludge lines since the ground garbage serves to carry the bits of bone and eggshells along. During August and September our troubles were increased when fruit pits joined the ranks of the bones and eggshells and it was only through the heroic work on the part of the treatment plant operating staff that we were able to keep the sludge lines clear.

Our present practice is to flush all digested sludge lines once each

day and we remove some 15 to 20 cu. ft. of assorted bones, eggshells and bottle caps each day. We experimented last fall with a small wooden settling tank on the roof of one digester through which the garbage sludge mixture passed before entering the digester. The results were encouraging and a considerable amount of bones and heavy material did settle out, the raw sludge thinning up the garbage enough to permit this result. We feel that a suitably designed mechanically cleaned grit chamber would eliminate a large part of our troubles from this source. Means would have to be provided to wash the grit since considerable heavy garbage particles would be dragged down with the

FIG. 3.—Receiving dock with can washer in background. Control panel for grinder and ejector also shows in background.

grit. Plans are under consideration to make such an installation. We are also installing a pipe line which would permit adding the garbage to the raw sludge just ahead of the grit chamber. Tests will then be made on the desirability of adding the garbage to the sewage rather than directly to the digesters. We also feel that this line will prove useful when the next fruit canning season rolls around.

Considerable trouble was experienced with the clogging of the digested sludge pumps, especially during the fruit canning season. Bits of bones would stick to the ball checks on the plunger pumps and prevent the balls from seating. The pump manufacturer provided smaller diameter valve seats on the theory that the higher velocity of flow would

carry the bone bits through the valve. This did not prove to be the case but by providing additional clearance for the ball checks we have nearly eliminated this operating difficulty.

Another serious problem connected with the digestion of garbage solids is the quality of the supernatant from the digestion tanks. Prior to handling garbage we obtained supernatants running under 0.5 per cent total solids which we could handle through the treatment processes without any apparent trouble. The addition of garbage increased the gas production tremendously and naturally the solids in the supernatant increased and now range from 2 to 2.4 per cent. We are able to handle this supernatant through the plant for as high as three weeks at a time but eventually we overload the aeration process and the activated sludge begins to bulk. Our digesters are operated as single-stage units and we are planning the necessary changes to permit stage digestion using two of the tanks for primary stage and two for final. This should result in a better quality of supernatant.

The preceding remarks would indicate a rather pessimistic case for the digestion of sewage and garbage solids. However, we have never had any trouble with the digestion of the solids. During the past year the daily average of solids added to the digester has been as follows:

	Total Solids Pounds	Volatile Solids Pounds	Per Cent Volatile
Sewage	19,400	11,800	61
Garbage	9,430	8,650	93
Combined	28,830	20,450	71

The digested sludge withdrawn has averaged 9.1 per cent solids and 48.1 per cent volatile solids and fulfills the requirements of a well digested sludge as outlined by the Committee of the Sanitary Engineering Division on Sludge Digestion of the American Society of Civil Engineers. The digested sludge does show bits of paper, can rubbers and some material of that nature introduced with the garbage which is not affected by the digestion process. The year's results would indicate a reduction in volatile content of 62 per cent and in total solids of 44 per cent which would indicate rather complete digestion. No trouble has been experienced in filtering the digested sludge except that we have noted that the moisture content on the filter cake increased from around 70 per cent to nearly 72 per cent but I am not prepared to state that this can be charged to the presence of garbage solids in the sludge.

The gas production has increased tremendously. When operating as a sewage plant our gas production averaged about 100,000 cu. ft. per day or 1.3 cu. ft. per capita per day based on our connected population of 75,000. This indicates a gas production of 8.5 cu. ft. per pound of volatile solids added to the digesters. During the past year the gas production has averaged 231,000 cu. ft. per day or 3.1 cu. ft. per capita.

This increase took place in slightly over a month. The gas production for the first month of garbage handling was 165,000 cu. ft. per day and 234,000 cu. ft. per day for the second month. The production varies about 50,000 cu. ft. during the week, dropping to a low point on Sunday and Monday and reaching a peak on Friday. This follows the rate of addition of garbage solids very closely since no garbage is added on Sunday and only about one-half of the average amount is added on Saturday. The quality of the digester supernatant also fluctuates with the gas production. The gas production per pound of combined sewage and volatile solids is 11.3 cu. ft. This figure checks results obtained experimentally at Flint, Mich. The grease content of digested sludge averages close to 7.5 per cent.

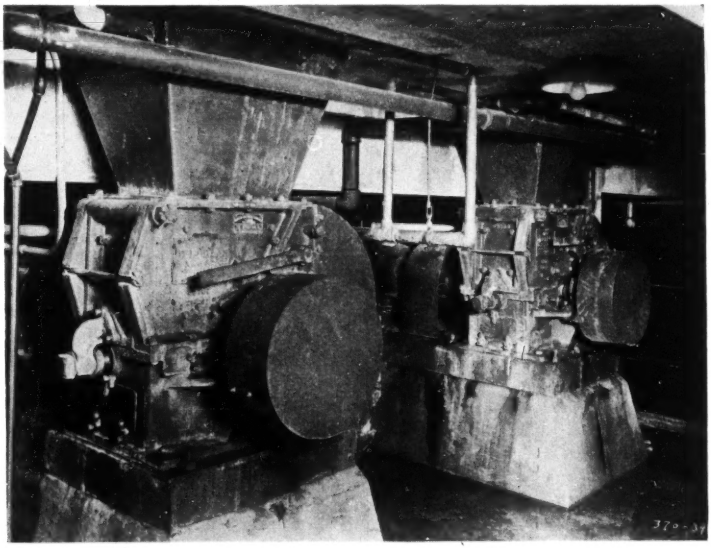


FIG. 4.—Garbage grinders located directly below receiving dock.

The addition of garbage did change the percentage of CO_2 in the sewage gas. Prior to adding garbage the percentage of CO_2 averaged about 30 per cent but since then it has averaged closer to 36 per cent. We have had no trouble with burning the gas in our boilers, incinerator and gas engine. The jacket water from the 240 H.P. gas engine has proved entirely adequate to heat the digestion tank to 85 to 90° F. During the coldest months of the winter when considerable frozen garbage is handled it is necessary to use the waste heat boiler to recover additional heat from the engine exhaust but during the balance of the year the jacket water alone is sufficient.

From our experience so far it would appear that the selection of fixed cover digesters equipped with sludge removal equipment was a wise one in view of the action of bones and eggshells. We also feel that the idea of adding the ground garbage directly to the digesters rather than to the sewage is the proper method to be used. Experiments by Babbitt have shown that when garbage is added to sewage approximately 59 per cent of the total solids goes into solution or colloidal suspension as well as 66 per cent of the garbage volatile solids. This method increases the load on the sewage treatment processes and also requires greater digester capacity since the solids introduced into

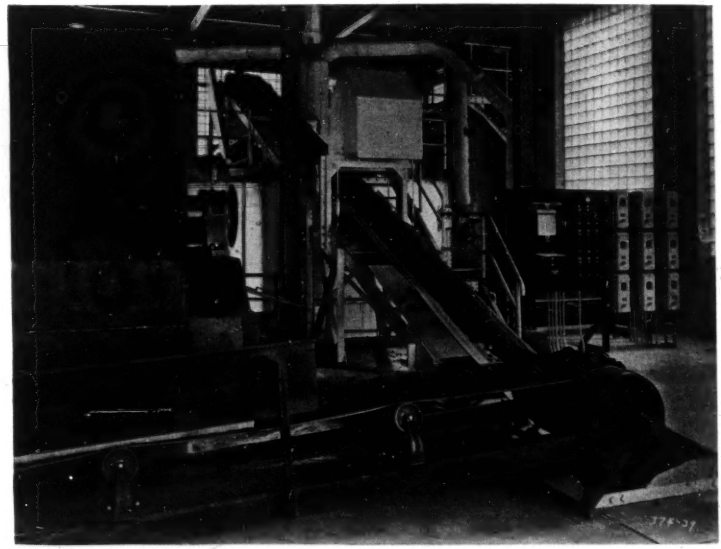


FIG. 5.—Vacuum filter cake discharging into multiple hearth rabble arm type of incinerator.

the garbage will occupy more space. This would tend to aggravate the supernatant problem. Experience at Aurora as reported by Sperry indicates the necessity of introducing solids to the digesters in as concentrated a form as possible.

CONCLUSIONS

To summarize briefly the results of our experience to date with handling sewage and garbage solids we feel that we can safely state that—

1. The sewage and garbage solids digest readily and thoroughly.
2. Gas production has increased 230 per cent.

3. Some provision must be made to remove bones, eggshells and fruit pits from the garbage solids before they are added to the digesters.

4. Account must be taken of the increased gas production in the design of digesters and sufficient capacity provided to handle the increased amount of volatile solids that must be handled.

5. Stage digestion is indicated as necessary to obtain a supernatant low enough in solids to permit return to the treatment plant.

GARBAGE ORDINANCE

No. 45

AN ORDINANCE relative to garbage and the collection and disposition thereof.

The City of Lansing ordains:

Section 1. Garbage, within the meaning of this ordinance, shall be construed to mean rejected food wastes, and to include every refuse accumulation of animal, fruit or vegetable matter, used or intended for food, or that attends the preparation, use, cooking, dealing in, or storing of, meat, fish, fowl, fruit or vegetables.

Sec. 2. From and after the passage and taking effect of this ordinance it shall be unlawful for any person to deposit or place any garbage, within the meaning of this ordinance, in any alley, street, river or other public place within the City of Lansing; nor shall any person deposit or place any garbage upon the private property, whether owned by such person or not, within the limits of the City of Lansing, unless the same shall be enclosed in a suitable can, vessel, tank or container, such can, vessel, tank or container to be perfectly water-tight, and so kept, with tightly fitting covers; which cover shall not be removed except when absolutely necessary: Provided, however, that any person who immediately destroys such garbage upon his own premises by cremation or otherwise to the satisfaction of the board of health or its health officer shall not be required to place such garbage in any such can, vessel, tank or container.

Sec. 3. Such can, vessel, tank or container shall be suitable and of convenient size to be handled by the garbage collector, and shall be kept on the ground level so as to be readily accessible for collection. Every such can, vessel, tank or container shall be promptly delivered to the garbage collector when called for, and no person except for such purpose of removal shall in any manner interfere with such can, vessel, tank or container, or with the contents thereof.

Sec. 4. **It shall be unlawful for any person to place in any such can, vessel, tank or container, any glass, crockery, tin, metal, ashes, paper, or wood or any poisonous substance whatever; nor shall any garbage be placed in any such can, vessel, tank or container until such garbage shall first have been drained of any excess fluids.**

Sec. 5. No person, firm or corporation other than the City of Lansing shall remove any garbage through the streets, alleys or other public places or ways of the City of Lansing.

Sec. 6. For the purpose of systematically and in a sanitary manner, collecting, removing and disposing of all such garbage, the superintendent of Public Works is hereby charged and empowered to superintend the same, and is hereby authorized and directed to secure competent help to promptly collect, remove and dispose of said garbage as herein contemplated. The superintendent of Public Works in the collection and disposal of the garbage of the city shall be subject to such rules and regulations as the city council by resolution may adopt.

Sec. 7. The cost of the collection and disposal of the garbage of the city, except for can service as hereinafter provided, shall be paid from the general city funds. The city shall provide the garbage cans or containers required by this ordinance and the superintendant of Public Works shall collect in advance from the users of such cans a service charge to help pay the cost and maintenance of the same as follows: **Two dollars ($2.00) for the period ending any fiscal year, except that if payment is made on or before May**

15, the service charge shall be one dollar and fifty cents ($1.50). The service charge for the balance of any fiscal year after November 1, shall be but one dollar ($1.00), and for the balance of any fiscal year after March 1, it shall be fifty (50c). Such persons as pay the service charge as provided for in this ordinance shall further agree with the garbage department of the City of Lansing that they will be responsible for loss of cans left for their use and will reimburse the city in case said cans are lost or destroyed by reason of the fault of the user thereof.

Sec. 8. Any person violating any of the provisions of this ordinance shall, upon conviction thereof, be punished by a fine not exceeding one hundred dollars and the cost of prosecution, and in default of the payment of such fine and cost such person shall be imprisoned in the city penitentiary until such fine and costs are paid, but not exceeding 60 days.

Sec. 9. This ordinance being deemed immediately necessary for the preservation of the public peace, health and safety is given immediate effect.

Sec. 10. The ordinance entitled, "an ordinance relative to garbage and the collection and disposition thereof," passed June 1, 1915, is hereby repealed.

Passed June 4, 1917, as amended April 19, 1926, and January 16, 1939.

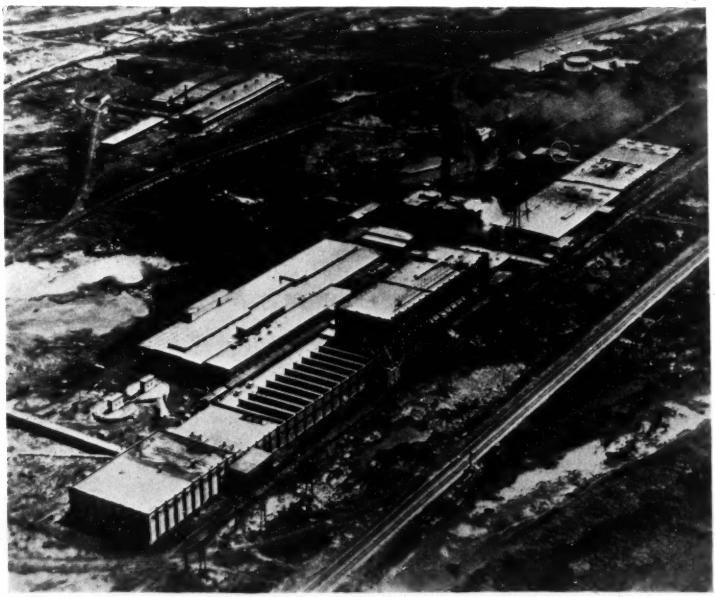
Industrial Wastes

TREATMENT OF TANNERY WASTES AT THE GRIESS-PFLEGER TANNERY, WAUKEGAN, ILLINOIS

By John W. Harnley, Frank R. Wagner and H. Gladys Swope

Chief Chemist and Research Chemist, Griess-Pfleger Tanning Co., and Chemist, North Shore Sanitary District

A cooperative investigation was begun in December, 1937, between the Griess-Pfleger Tanning Company and the North Shore Sanitary District for the purpose of studying the flow and characteristics of the tannery waste effluent, in order to determine whether further treatment of this waste should be provided at the Waukegan sewage treatment works. This treatment plant is of the Imhoff type with chemical treatment in the summer, and has been described by one of us.[1] The tan-



Aerial view of the Griess-Pfleger Tanning Company. The Dorr settling tanks appear in the lower left hand corner.

nery installed a treatment plant for their wastes in 1917. This consists of a coarse bar screen and two Dorr settling tanks, each of 170,000 gallons capacity. The clarified effluent has been discharged into Lake Michigan.

The Griess-Pfleger Tanning Company

The tannery is located in the northeastern section of Waukegan on Sand Street, 3000 ft. west of Lake Michigan. When operating at full capacity there are 650 employees. At maximum capacity approximately 670,000 lb. of green salted domestic cattle hides are tanned per week. At an average of 40 lb. per hide (15 to 60 lb. hides used) this would be 16,875 hides or 33,750 sides and will produce more than one-half million sq. ft. of shoe leather. This goes primarily into shoe uppers and is divided into the following classifications:

a. Work shoe upper leather
   1. Work Elk in black, white and colors
   2. Retan in black and colors

b. Dress shoe upper leather
   1. Russia side leather in black, white and colors
   2. Sport Elk side leather in black, white and colors
   3. Buck side leather in white and colors
   4. Heavy collegiate designed leathers in black and colors
   5. Waterproof upper leather for rough sporting shoes

c. Splits—By product
   1. Quarter lining for shoes in black, white and colors
   2. Retan splits for lower grade work shoe uppers
   3. Gusset stock for tongues of shoes
   4. Glove stock for gloves

The principal tanning process used is the chrome process. This process and those previous and subsequent to tanning are, with a few exceptions which will be especially noted, essentially the same throughout the industry.

The hides, as received at the tannery in the green-salted state, are first trimmed, split into sides and then washed. A twenty-four hour soak in fresh water with salt added follows. After this operation the hides are soft and in the same physical condition as when they were flayed. The adipose tissue is now removed from the flesh side (soak-fleshing). The hides are then soaked for two or more days in a saturated lime liquor with excess lime, to which chemicals known as sharpening agents or accelerators may be added to shorten the time required to loosen the hair. The principal sharpening agents in use at present are sulfides and amines. Most tanneries use some sulfide but for a number of years this tannery has used dimethylamine only. This has a very important effect on the character of the waste effluent, which will be discussed more fully later.

After liming and unhairing the hides are washed to remove most of the lime remaining in them. They are then bated. This operation has two functions and thus the bating solution has two components: one a deliming agent such as ammonium sulfate to remove the lime not

taken out by the wash; and the other a proteolytic enzyme such as trypsin to remove, wholly or in part, proteins such as elastin or keratose. Soaking, unhairing, deliming and bating are all carried out in the department known as the beam house where the largest amounts of water are used and thus the largest volume of waste effluent originates there. This is also the source of the greatest amount of suspended and soluble matter and is particularly characterized by its high alkalinity, being practically saturated with lime.

Tan House.—After coming out of the bate the hides are treated with salt and acid (pickling) preparatory to tanning with chromium sulfate. In simple terms the tanning agent is basic chromium sulfate, $CR_2(SO_4)_2(OH)_2$ and is prepared by reducing a mixture of sodium bichromate and sulfuric acid with glucose. The process of tanning requires from several hours to several days depending upon the equipment used and the type of leather produced. Treatment with alkali, such as sodium bicarbonate, usually follows to neutralize excess acid, and "set" the tannage. Although the waste tan liquors contain large amounts of acid and highly colored (green) chromium salts, there is present at all times in the beam house waste more than sufficient lime to completely neutralize the acid and precipitate the chromium salts.

After chrome tanning, some of the hides are given a second tanning (retanning) with vegetable extracts. These are principally evaporated extracts of woods or barks that contain vegetable tannins. Quebracho, chestnut, gambier and oak are typical examples. Sometimes these are used with synthetic materials of similar chemical structure known as syntans.

Due to the objectionable red color imparted to the wastes by these materials, all such wastes are segregated and lagooned over old sludge beds which act to some extent as filters. The colorless filtrate is then pumped into the general waste. (See the section on waste disposal equipment for further discussion.)

After tanning, the excess moisture is pressed from the hides and they are leveled off in thickness by splitting and shaving.

A wide range of aniline dyes and natural dye woods are used to color the leather. The color mill wastes are highly colored but their relative volume is small and the coloring matter is removed by the alkalinity and suspended solids in the beam house wastes.

The final operation prior to drying and finishing is known as fat liquoring (stuffing, in the case of heavy leathers). It consists of treating the leather with emulsions in water of various animal, fish, vegetable and mineral oils for the purpose of keeping the leather soft and flexible after it is dried. The oils are so completely taken up from the fat liquor baths by the leather that no noticeable amounts of oils are in the waste even before settling in the Dorr tanks.

The only subsequent source of wastes is from the finishing departments. Many materials are used in making finishes for leather. The finishes or coatings commonly used are of three primary types; varnish,

lacquer and water dispersed. At the present time most of the leather manufactured in this tannery is finished with the latter type. These finishes are essentially water dispersions of pigments and dyes, with binders such as casein, glue or synthetic resins. The mixtures are usually brushed or sprayed on to the leather by hand or machine and do not find their way into the waste except through cleaning of equipment.

The concentration of the waste is considerably affected by an unusual factor, that of dilution by seepage water. This is due to the fact that the plant is surrounded on three sides by low lying marshy soil. With an average lake level of 580.73 ft. above sea level, Sand Street (where the tannery is located) is only 8.47 ft. above lake level. On June 14, 1940, the ground water level was found to be 5 ft. above city datum or 3 ft. below Sand Street. This condition causes the effluent to be diluted with considerable quantities of seepage water, which reaches volumes as high as 3,500,000 gallons per week. This volume has been considerably reduced and subjected to some control during the past two years by local drainage and by reducing and controlling the volume of sludge lagooned. During 1939 the volume varied between no flow and an average monthly high of 1,970,000 gallons per week, and was primarily a function of the weather. At maximum capacity, water consumption is 7 million gallons per week. Thus the effluent would be between 7 and 8.97 million gallons per week as affected by volume of seepage, and the dilution would be between 0 and 29 per cent.

Historical

The waste disposal problem was attacked even before the completion of the tannery in 1916 and a study of the wastes has continued intermittently but with a concentration of continuous activity during the past five years.

This latter activity was initiated when the State of Illinois Sanitary Water Board, as part of its state wide survey of industrial wastes, asked permission to make a study of the waste effluent from this plant. On October 29 and 30, 1936, they made a 48-hour survey. Samples of the individual components of the influent to the Dorr tanks were collected and also two successive 24-hour composites of the Dorr tank influent and effluent. Volumes and chemical characteristics were determined.

The report of this survey led the management, which has always had the desire to understand these problems, to instruct their laboratory to develop and follow a program of investigation so as to be able to meet criticism and suggestions with reasonable action.

In the fall of 1937, the North Shore Sanitary District, which has recently completed a sewage disposal plant and laboratory in Waukegan, agreed to cooperate in this study as outlined in the opening paragraph. In the course of the study three sets of samples were taken; throughout one week in December, 1937, the same in October, 1938, and on two days in May, 1939. The data presented in this paper are part of the information gained from results of analyses of these samples.

Table I presents the analytical data collected on the effluent discharged to the lake prior to this investigation. The type of samples and the sources of the analyses are indicated.

The analyses dated November 27, 1916 through December 7, 1916 indicate the characteristics of the wastes before the installation of the settling tanks. It was this work of Pearse and Greeley that led up to installation of the tanks.

The analyses dated September 23, 1924, January 30, 1930 and January 31, 1930, show a comparison between day and night flow samples.

The data for March 7, 1929, April 24, 1930, May 2, 1930, March 17, 1930 to May 12, 1930, June 18, 1936 and October 29, 1937 to November 8, 1937, are all 24-hour composites with both tanks in operation and are comparable.

The analyses dated March 17, 1930 to May 12, 1930 show the greatest variation observed by weekly 24-hour composites over a seven-week period.

Those dated August 17, 1934 show the greatest variations found in phenolphthalein alkalinity, a function of dissolved lime content, over a 24-hour period.

The results on October 30, 1936 and October 29, 1937 through November 8, 1937 show a comparison between the two settling tanks when the load was unevenly distributed, the north tank carrying the greater load in both cases.

The analyses dated October 29, 1937 to November 8, 1937 and November 9, 1937 to December 4, 1937 show a comparison between the use of one or two tanks. The plant production was uniform throughout this period.

The significance of the B.O.D. figures will be discussed later.

Tannery Waste Treatment

Equipment.—Since it is impossible to suspend tanning operations for more than a short period of time without damage to the stock in process, the equipment for handling the tannery waste was designed with full consideration for any emergency such as that due to mechanical failure.

Suitable ducts allow the waste to flow by gravity to a centrally located sump 20 ft. long, 17 ft. wide and 10 ft. deep. A coarse bar screen retains large objects which might otherwise be swept into the pump intake and cause damage to the pump.

Any one of three pumps may be employed to deliver the waste to the dividing chamber at the Dorr clarifiers. Two of the pumps are 8-in. A. B. Wood patent vertical centrifugal sewage pumps, driven at 490 R.P.M. by directly connected 35 H.P. motors. The third pump is a No. 5 Swaby figure 1902 V-belt driven centrifugal pump operated by a 15 H.P. 1740 R.P.M. motor at 635 R.P.M.

One of the large pumps is used on peak loads and the small pump adequately handles the normal volume. The second large pump is a stand-by unit.

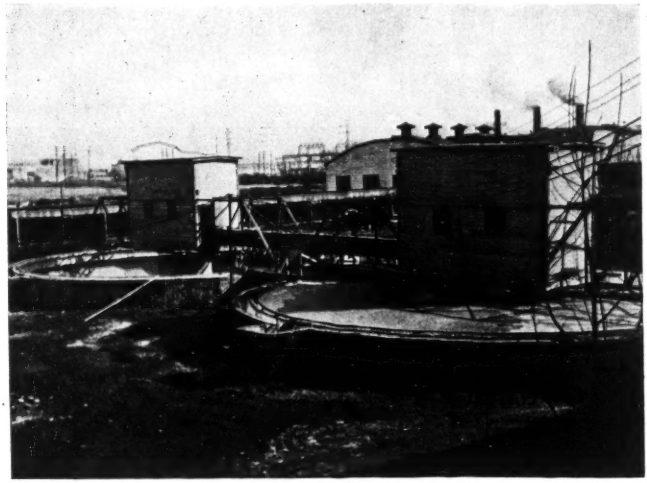
TABLE I.—*Review of Previous Analytical Data on Plant Effluent—Results expressed as p.p.m.*

Date	Total Solids	Susp. Solids	Vol. Susp. Solids	as $CaCO_3$		Org. N	NH_3 N	5 day B.O.D.	Sample	Analysis by
				Alk. M.O.	Alk. P					
11–27–16	—	2016	1368	—	—	—	—	—	10 hour working day composite corresponds to present influent to settling tanks	Pearse and Greeley
12– 4–16	—	6432	5112	59.5	—	28.0	30.0	—		
12– 7–16	—	—	—	239.4	—	33.0	35.0	—		
9–23–24	—	184	138	—	—	30.3	7.3	223	Day flow composite	Pearse, Greeley and Hansen, Dr. Mohlman
9–23–24	—	144	124	—	—	29.7	9.5	235	Night flow composite	
3– 7–29	3600	200	—	800.0	—	—	—	—	24 hour composite	Griess-Pfleger Tanning Co.
1–30–30	3842	352	232	872.0	712.0	17.9	12.3	210	Day flow composite	Pearse, Greeley and Hansen, Dr. Mohlman
1–30–30	4031	412	320	632.0	372.0	1.1	7.3	200	Night flow composite	
1–31–30	3825	328	232	744.0	502.0	11.5	10.3	140	Day flow composite	
4–24–30	—	187	—	647.0	496.0	—	—	—	24 hour composite	Griess-Pfleger Tanning Co.
5– 2–30	—	166	—	524.4	379.8	—	—	—	24 hour composite	
3–17–30	—	214	—	855.0	685.0	—	—	—	Max.	J. A. Wilson
to	—	102	—	305.0	150.0	—	—	—	Min. 7–24 hour composites. One per week	
5–12–30	—	157	—	638.0	447.0	—	—	—	Aver.	
	—	—	—	—	1024.	—	—	—	Max.	
8–17–34	—	—	—	—	127.0	—	—	—	Min. 24 samples at one hour intervals	Griess-Pfleger Tanning Co.
	—	—	—	—	528.0	—	—	—	Aver.	
6–18–36	2940	119	—	565.0	338.0	—	—	—	24 hour composite	Griess-Pfleger Tanning Co.
10–29–36	3600	150	70	—	—	—	—	105	N. and S. Tanks 4:00 A.M. to 7 P.M. composite	Illinois State Sanitary Water Board
10–30–36	4200	110	56	—	—	—	—	125	N. Tank 64% Flow	
10–30–36	4100	98	82	—	—	—	—	105	S. Tank 36% Flow	
10–29–37	—	198	—	—	—	—	—	—	Max.	Griess-Pfleger Tanning Co.
to	—	97	—	—	—	—	—	—	Min. 24 hour composites. Samples on 5 separate days (1*a*)	
11– 8–37	—	138	—	—	—	—	—	—	Aver.	
10–29–37	—	129	—	—	—	—	—	—	Max.	Griess-Pfleger Tanning Co.
to	—	32	—	—	—	—	—	—	Min. 24 hour composites. Samples on 5 separate days (1*b*)	
11– 8–37	—	91	—	—	—	—	—	—	Aver.	
11– 9–37	—	197	—	—	—	—	—	—	Max.	Griess-Pfleger Tanning Co.
to	—	51	—	—	—	—	—	—	Min. 24 hour composites. Samples on 11 separate days (2)	
12– 4–37	—	151	—	—	—	—	—	—	Aver.	

1*a*—North tank only— 60% of flow 61 packs per week
1*b*—South tank only— 40% of flow 61 packs per week
2 —South tank only—100% of flow 61 packs per week
Suspended solids 394 p.p.m. on first day after breakdown of North tank

A float switch operating through a suitable arrangement controls any one of the pumping units in such a way that evacuation is begun when the sump contains about 9,000 gallons and ceases when the level has dropped to 5,500 gallons. The upper level is the highest practicable to maintain satisfactory drainage of the lime pits and soak vats. The lower level is the lowest level that will insure the intake to the pump being under water at all times.

This arrangement permitted a simple recording system to be effected by connecting a small step-down transformer and a bank of four Mazda lamps in parallel with the motor of each of the regularly used pumps. Each transformer operates a self-starting electric clock, and the banks of bulbs are arranged about the control bulb of a Foxboro



Dorr settling tanks at the Griess-Pfleger Tanning Company.

temperature recorder. Since the proximity of the lamp bank to the temperature recorder bulb controls the height of the peaks of the chart, by placing one bank of lamps closer than the other, it is possible to differentiate between the records of the two pumps. Daily clock readings are taken which give the total daily pumping time for each pump and the temperature recorder furnishes a permanent record of the operation of either pump at any time.

By partially draining both settling tanks, closing the drain valve and measuring the rise in level in the tanks for a pumping time indicated by the clocks in the recording system it was possible to obtain the pumping rate of each pump and at the same time the distribution of flow between the two Dorr clarifiers.

Thus the volume of waste can easily be determined for any period, and composite sampling is accurately accomplished.

The 14-in. pipe line leading from the sump pumps to the Dorr clarifiers is 570 ft. long. This line discharges into an open dividing chamber about 20 ft. above the lower sump level. Adjustable dividers regulate the division of flow by gravity into the two Dorr clarifiers.

The capacity of each Dorr clarifier is 170,000 gallons. They are 60 ft. in diameter, 10 ft. 4 in. deep at the center and 6 ft. 6 in. deep at the edge. A baffle about the rim of each tank retains any floating matter. The effluent flows into a catch basin and thence into the street sewer.

The detention periods reported in Tables II and III were calculated from the theoretical capacity of 170,000 gallons per tank. Settling periods were checked by adding dye to the influent to the tanks and measuring the volume of flow until the appearance of the dye in the effluent. At the time of this test the flow was evenly divided between the two tanks and the same results were obtained from both tanks. The test indicated that the detention periods were equivalent to volumes as follows:

Minimum	108,000
Maximum	228,000
Effective	160,000
Average	Slightly more than 160,000

As the bulk of the dye came through at 160,000 gallons this is taken as the effective equivalent and as more dye came through after this point than before, the average is believed to be equivalent to a figure slightly over 160,000 gallons. These figures are in fair agreement with the theoretical volume of 170,000 gallons.

The sludge from each tank as carried to the center by the scraper blades is pumped to the sludge lagoon by a Hayton No. 34 special vertical single plunger pump having an 8 in. cylinder and a 12 in. stroke. All valves on the pump are ball valves. A 10 h.p. motor at 1165 r.p.m. drives each pump through a belt and gear system at 30 strokes per minute. The pumping rate, confirmed by test, is 80 gallons per minute.

Sludge disposal is not a problem since there is considerable area of marsh to be filled close to the Dorr clarifiers. The procedure is to deposit the sludge by a movable 8-in. pipe. The sludge bed formed is drained by ditches leading back to the waste disposal system. When this bed reaches a given height the pipe is moved to a new location.

A small portion of the tannery waste contains coloring matter from spent tanning extracts. By the simple expedient of piping all such waste to an old sludge bed, drained by ditches, the bed becomes a filter which effectively removes the color by chemical action with the alkaline sludge and mechanical filtration. The decolorized waste then goes into the general waste.

As mentioned previously, one large sewage pump at the sump is held in readiness in case of failure of the other. In case of power failure,

a steam siphon in the pump pit keeps the seepage water level low enough to protect the motors, and a portable high speed gasoline pump may be brought in to keep the sump level low. (In case of freezing, breakage or clogging of the 14-in. pipe line leading from the sump to the Dorr clarifiers, an emergency line may be used which empties into a ditched swamp.)

Provision has been made at the Dorr clarifier dividing chamber to turn the entire flow into either tank, enabling the other one to be drained for repairs or cleaning.

It is difficult to conceive of any emergency arising that would curtail processing due to the sewage system being disabled. The disruption of the power supply for more than a short period would stop production for other reasons.

Flow vs. Production and Distribution of Flow

Flow vs. Production.—The weekly totals for packs soaked, metered water and influent to the Dorr tanks are shown in Fig. 1. The period from December 2, 1937 to January 18, 1939, includes the two periods when the major part of the following analytical data was collected. Set No. 1, December 2, 1937 through December 13, 1937, includes one of each of the seven days of the week but not a continuous week. Set No. 2, November 1, 1938 through November 7, 1938, is a continuous week.

The two days, Monday and Tuesday, May 15, 1939 and May 16, 1939, Set No. 3, were part of a special investigation and are included here for comparative purposes.

Production is spoken of in terms of packs (4200 lb. green-salted hides trimmed weight) going into soak. These packs remain units until the end of the unhairing process. Over a period of uniform production, this figure as a weekly total is significant in connection with waste influent. For single days or even for isolated weeks it has no significance.

About 75 per cent of the influent originates in the beam house and the major part of this volume is a function of packs taken out of lime (unhaired). However, about 45 per cent of the solids in the influent originates in the lime liquors and these are not dumped on the same day that the packs are taken out of them but during a period of uniform production lime liquors dumped per week will equal packs in soak per week. Thus the characteristics of any one day's influent are a function of two major factors, the packs taken out of lime and the number of lime liquors dumped and are also a function of a number of minor factors such as packs going in and out of soak and production in other departments, the more important in consideration with influent being the tanning, coloring and fat-liquoring departments.

In Fig. 1, production is shown in terms of packs going into soak. There is a noticeable lag of about two weeks in the figures for metered water used and influent. The period from April 13 through January

18, 1939 begins with zero production and ends with maximum production. The effects of the various holidays are clearly shown, although those that occurred during periods of increasing production are partially obliterated. Seepage water is not metered but is considered to be the difference between influent and metered water. However, it is known to be in excess of this because more water is evaporated from the leathers in drying than is introduced in the hides. Also other losses are known to occur so that with zero seepage the volume of influent should be less than the volume of metered water. The period beginning October 19 through November 9, 1938, shows influent to be about 0.9 million gallons per week less than metered water. We know that during this period seepage was actually greatly reduced and these figures may be an indication of the amount of metered water that did not find its way into the influent.

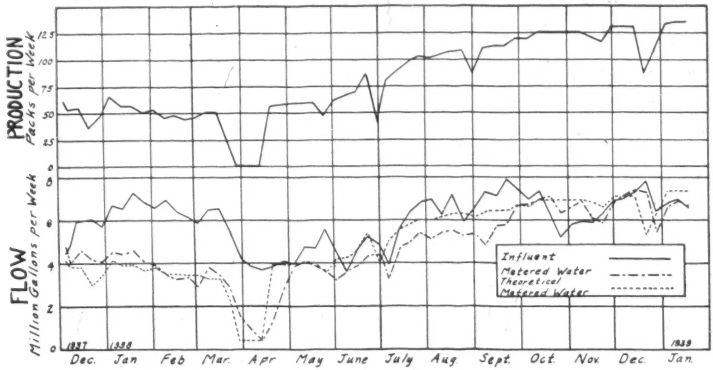


FIG. 1.—Record of production and volumes of water used and influent to Dorr tanks.

The theoretical metered water figures were obtained from a study of continuous daily records over a 25-month period, December, 1937, through December, 1939. These data are presented in Fig. 2, and show the relationship between production in terms of packs soaked per week and the amounts of metered water used and waste pumped.

The metered water figure for zero production was obtained during the third week of a continuous shut down. The other metered water figures were obtained by taking the volumes for the second week of each month. This particular week was taken because it coincided with the third week of zero production and this third week gives a significant figure because by this time all of the water consuming operations had been closed down. It is important to realize that production is in terms of packs going into soak and does not necessarily bear any relation to production in the rest of the plant because it takes two weeks to put this

stock through the soaking, unhairing, tanning and fat-liquoring operations and it takes six weeks to put the stock through all of the processes.

The amount of influent may be any value found in the shaded portions and under unusual conditions may be more or less. The maximum value in the shaded portions (volume of influent) was determined from the highest value found during each of the 25 months. These figures indicate that the seepage (influent minus metered water) is normally between 0 and 1.97 million gallons per week and during periods of normal plant operation is primarily a function of the weather. The period October 19 through November 9, 1938, is the only one in our experience where the volume of influent ran consistently under the volume of metered water.

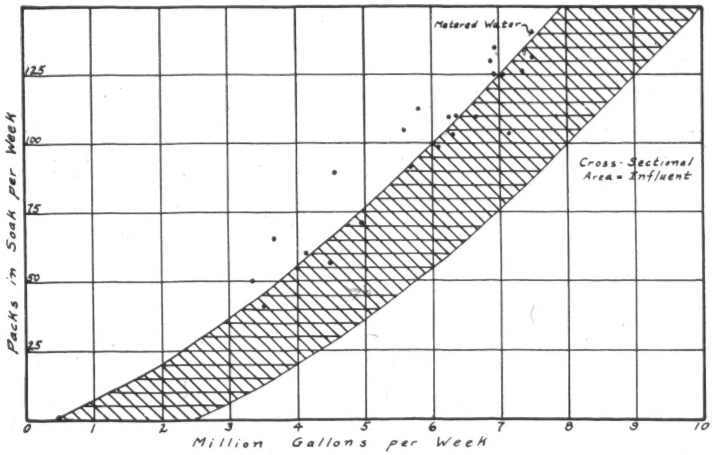


FIG. 2.—Relation between production and volumes of water used and influent to Dorr tanks.

Distribution of Flow.—The daily distribution of flow in terms of per cent of weekly total is shown in Fig. 3.

Set No. 1 represents a period of production 43 per cent of capacity and Set No. 2 represents a period of production 93 per cent of capacity. (At the time of this report 135 packs are considered 100 per cent.) Both sets of data show the same general distribution. At low production levels (No. 1) Sunday and Saturday are minimum days. Monday is the maximum day with the load decreasing throughout the week. At high production levels (No. 2) Monday is again the maximum day but the decrease throughout the week is much less and there is a sharp decrease in the relative load on Sunday.

Figure 4 shows the same data broken down into hourly flow (3 hr. moving average) and shown as per cent of weekly flow.

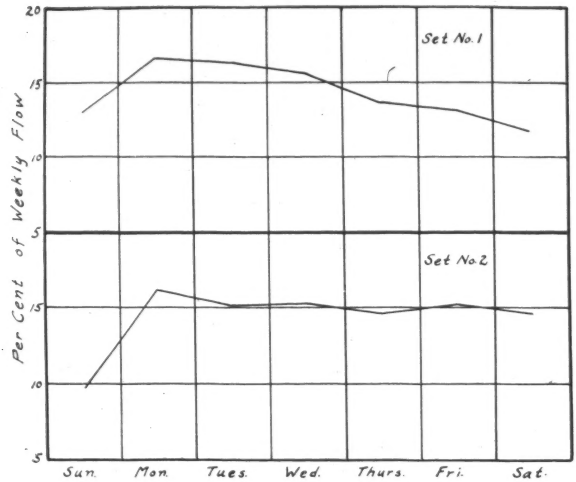


FIG. 3.—Distribution of weekly flow by days (influent to Dorr tanks).

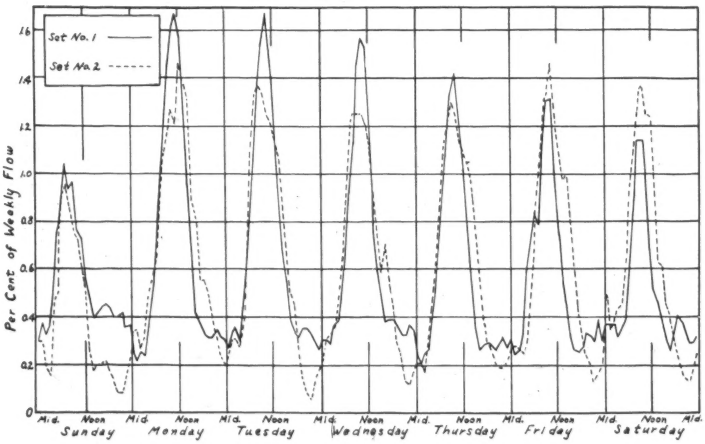


FIG. 4.—Distribution of weekly flow by hours (influent to Dorr tanks).

The peak load occurs between 9 A.M. and 12 Noon on week days and slightly earlier on Saturday and still earlier on Sunday. At low production (No. 1) the peak loads decrease throughout the week while at higher production levels (No. 2) the peak loads decrease through

Wednesday and increase again on Friday and Saturday. The peak load on Sunday is distinctly lower in both cases. The daily duration of peak loads is longer at the higher production levels. The minimum loads of Set No. 2 are lower than in Set No. 1 because less seepage was being pumped during this period. The ratio between minimum and maximum loads is about 1 to 7 but the maximum variation is 1 to 33.

Production vs. Amount of Waste Material.—Table II shows the daily production in the water consuming (influent producing) departments on the days involved in the three sets of data presented.

An examination of Table II shows that from one day to another there is a large variation in the amount of hides going through a particular operation and that in many cases the total for a week is not the same for different operations. To bring out the relationship between production and the amounts of material found in the influent it is necessary to weight the value of the production at the above operations. Also the weight of the operation may be different for different components in the influent. For instance, the stock coming out of lime is the source of 20 per cent of the total solids and 30 per cent of the suspended solids in the influent.

Empirical equations have been developed from the data available. From these equations can be calculated the weighted production in relation to the specific components in the influent and the amounts of these components that should be found in the influent. The weighted production figures in terms of equivalent packs are tabulated at the bottom of Table II. The ratios between the amounts of the various components found by analysis and the amounts calculated from the equations are shown in Table III.

The same symbols, as follows, are used in all the equations given.

P = Packs through the given operation per day (See Table II)
P_1 = In soak
P_2 = Out of soak
P_3 = Out of lime
P_4 = Lime pits dumped
P_5 = Out of bate
P_6 = Out of tan
P_7 = Out of fat liquor
K = Constant for any comparable set of data and is determined by the nature of the hides being processed and the processes being used.

When $K = 1$ the equations give the weighted production relative to the specific component in terms of equivalent packs, *e.g.* if the weighted production is 10 equivalent packs, this means that the amount of the material in the influent is the same as it would be if 10 packs had gone through all the operations.

Total Solids.—Equation No. (1):

$$[.2\,P_1 + .05\,P_2 + .2\,P_3 + .45\,P_4 + .01\,P_5 + .05\,P_6 + .04\,P_7]\,K = \text{Lb. total solids per day}$$

The constant K for Set 1 = 2950
Set 2 = 2250
Set 3 = 2225

TABLE II

Plant Production per cent of capacity.....		43% (58 packs per week)								93% (125 packs per week)								74% (100 packs per week)		
Days of week.....		S	M	T	W	T	F	S	Total for week	S	M	T	W	T	F	S	Total for week	M	T	Total for 2 days
Date.....		12–12 1937	12–13	12–7	12–8	12–2	12–3	12–4		11–6 1938	11–7	11–1	11–2	11–3	11–4	11–5		5–15 1939	5–16	
Operation	Pack Weight	Packs								Packs								Packs		
In Soak.....	(1)	10	10	5	5	10	10	8	58	21	22	12	7	21	21	21	125	11	0	11
Out Soak.....	(1)	11	10	6	5	5	10	10	57	21	21	22	12	7	21	21	125	21	11	32
Out Lime.....	(1)	0	14	9	12	10	10	6	61	0	21	21	21	21	21	20	125	21	21	42
Lime pits dumped.....	(1)	11	11	8	6	4	5	10	55	21	21	21	22	12	7	21	125	17	21	38
Out Bate.....	(2)	0	14	9	12	10	10	6	61	0	22	21	21	21	21	19	125	12	21	33
Out Tan.....	(2)	4	6	4	9	10	10	10	53	19	7	14	22	21	21	21	125	11	12	23
Out Fat Liquor.....	(3)	0	14.9	14.4	13.9	12.9	5.9	0	62	0	18.3	23.3	24.8	22.8	21.8	16.8	127.8	21.3	20.3	42
Average packs per period									58								125			32
Weighted Production																				
Total Solids.....	E-1*	7.70	11.29	7.57	7.48	7.17	7.59	8.36	57.2	15.65	20.4	18.99	18.40	16.32	14.73	20.61	125.1	16.62	15.82	32.4
Suspended Solids.....	E-2*	6.31	11.59	8.12	8.52	7.10	7.30	8.20	57.1	13.24	19.51	20.16	21.28	16.45	14.04	20.77	125.5	17.63	19.34	37.0
Nitrogen.....	E-3*	5.75	12.00	7.45	8.35	8.55	9.00	7.60	58.7	10.83	19.29	18.30	18.47	19.32	18.94	20.05	125.2	14.04	15.12	29.16
B.O.D.....	E-4*	6.77	12.60	8.24	8.61	7.72	8.40	8.51	60.9	—	—	—	—	—	—	—	—	17.38	18.22	35.60

Pack Weights

(1) 4200 lb. Green Salted Hides (trimmed weight)

(2) 4000 lb. White Weight equivalent to above

(3) Estimated equivalent to above.

* Equations 1–2–3–4, respectively.

TABLE III.—*Relation between Materials in Influent and Production as Pounds per Pack*

	Set 1				Set 2				Set 3			
	58 packs per week				125 packs per week				32 packs per 2 days			
	Total Solids	Susp. Solids	Total N	B.O.D.	Total Solids	Susp. Solids	Total N	B.O.D.	Total Solids	Susp. Solids	Total N	B.O.D.
Pounds per week or period (1)	157,849	35,969	2,623	17,245	266,657	51,179	6,819	—	71,882	15,488	1,862	4,945
Pounds per pack	2,721	620	45.2	297	2,132	409	54.6	—	2,246	484	58.2	155
Calculated pounds per pack (2)	2,950	625	45.0	240	2,250	420	56.0	—	2,225	420	64.0	145
Ratios												
Pounds per day by analysis (1) / Pounds per day by calculation (2)												
Sunday	1.02	1.04	1.04	1.16	0.99	1.13	1.01	—	—	—	—	—
Monday	0.99	1.26	1.12	0.92	0.61	0.79	0.86	—	1.02	1.05	1.02	0.94
Tuesday	1.04	1.08	1.07	0.90	1.01	0.99	1.06	—	0.97	0.95	0.97	1.08
Wednesday	0.96	0.90	0.57	1.00	1.04	0.94	1.01	—	—	—	—	—
Thursday	0.98	0.98	1.42	2.99	0.95	0.99	0.98	—	—	—	—	—
Friday	0.99	1.06	0.93	1.06	1.17	1.22	1.01	—	—	—	—	—
Saturday	0.59	0.63	0.74	0.94	.95	0.87	.90	—	—	—	—	—

(1) Derived from data in Table IV.
(2) Derived from equations 1–2–3–4, respectively.

Note the divergence between the constants used for Set 1 against Sets 2 and 3 and the similarity between the constants used for Sets 2 and 3. There were no substantial changes in process between the dates of Sets 2 and 3 but there were such changes between the dates of Sets 1 and 2 and of a nature in agreement with the change in the constant. In other words we would expect to find more waste material per pack in 1937 than at the end of 1938.

Suspended Solids.—Equation No. (2):

$$[.03\ P_1 + .01\ P_2 + .3\ P_3 + .5\ P_4 + .01\ P_5 + .10\ P_6 + .05\ P_7]\ K = \text{Lb. suspended solids per day}$$

The constant K for Set 1 = 625
Set 2 = 420
Set 3 = 420

Again we have the divergence between the constants used for Sets 1 against Sets 2 and 3.

Nitrogen.—Equation No. (3*a*):
Set 1 only

$$[.3\ P_1 + .05\ P_2 + .2\ P_3 + .2\ P_4 + .25\ P_5]\ K = \text{Lb. nitrogen per day}$$

The constant K for Set 1 = 45

Note that at the time of Set 1, all of the nitrogen originated in the beam house.

Equation No. (3*b*):
Sets 2 and 3 only

$$[.2\ P_1 + .03\ P_2 + .10\ P_3 + .15\ P_4 + .32\ P_5 + .15\ P_6 + .05\ P_7]\ K = \text{Lb. nitrogen per day.}$$

The constant K for Set 2 = 56
Set 3 = 64

Note that at the time of Sets 2 and 3, the beam house is no longer the source of all the nitrogen, that 20 per cent now originates outside the beam house. This is due to definitely known process changes. The increased constant used for Set 3 is believed to be due to a change made in the beam house process.

B.O.D.—Equation No. (4):

$$[.15\ P_1 + .05\ P_2 + .25\ P_3 + .40\ P_4 + .15\ P_5]\ 1.05\ K = \text{Lb. B.O.D. per day}$$

The constant K for Set 1 = 228
Set 2 = No data
Set 3 = 138

Again we have a higher constant for Set 1 than for Set 3. However, it is believed that there is not sufficient data to definitely locate the values for equation 3. Note that equation 3 indicates that 95 per cent of the B.O.D. originates in the beam house and then principally from the lime liquors and limed stock. Independent work, beyond the scope

of this paper, on individual processes indicated that about 95 per cent of the B.O.D. originated in the beam house.

Alkalinity.—There is no relationship between production and alkalinity. Lime is used in such quantities that there is nearly always undissolved lime in the influent. This continues to dissolve as the waste passes through the disposal system. Frequently the effluent from the settling tanks is found to have a higher pH than when it entered the tanks.

Efficiency of Dorr Settling Tanks

The purpose of the detailed study of the tannery wastes, as made by the tannery and by the North Shore Sanitary District was to determine the work done by the tannery Dorr tanks, and to indicate whether or not the effluent should be re-settled in the Imhoff tanks of the Waukegan sewage treatment works.

Sampling.—The first three tests of Set No. 1 (December 2, 3 and 4, 1937) were divided into five sections, whereas, the rest of the sampling in Set No. 1 was divided into four sections. Samples were collected at frequent * intervals during the 24 hours and were composited into sections, each section representing as nearly as possible equal flow.

Set No. 2 was divided into three sections, each section again representing equal flow. With these sections, the middle or C section covered the period of peak flow. The data derived from these sections indicated that they served no useful purpose, so the samples for Set 3 were not subdivided into sections. Also in Set No. 2, separate effluent composite samples were made from the north and south tanks. Only minor differences appeared, so weighted averages are reported.

The sectional composites were as follows:

Section	Set No. 1 (1st 3 days)	(Last 4 days)	Set No. 2
A	6:00 A.M.– 8:40 A.M.	6:30 A.M.– 9:00 A.M.	12:00 M. –9:00 A.M.
B	8:40 A.M.–11:00 A.M.	9:00 A.M.–12:00 N.	9:00 A.M.– 1:00 P.M.
C	11:00 A.M.– 3:00 P.M.	12:00 N. – 8:00 P.M.	1:00 P.M.–12:00 M.
D	3:00 P.M.–12:00 M.	8:00 P.M.– 6:00 A.M.	—
E	12:00 M. – 6:00 A.M.	—	—

All composites, sectional and 24-hour, were composited according to flow.

Analyses were run on the sectional composites as well as on the 24-hour composites.

For the purpose of this discussion, only the results of the 24-hour composite samples have been tabulated as these are representative of all of the data. The results of these analyses will be found in Table IV.

Analyses and Methods.—Total solids, total and volatile suspended solids, biochemical oxygen demand, total and phenolphthalein alka-

* In Sets No. 1 and 3, 25 samples were collected over the 24-hr. period, each sample representing as nearly as possible equal flows.
In Set No. 2, 30 samples were collected.
When sludge was pumped 12 hours per day, samples were collected at 1-hr. intervals. When the daily pumping period was less, samples were collected at 5-min. intervals. In all (influent, effluent and sludge) 2088 samples were collected.

TABLE IV.—*24-hour Composite Samples*

Day	Date	Flow M.G.D. Inf.	Det. Per. Hr.	Total Solids p.p.m. Inf.	Total Solids p.p.m. Eff.	Suspended Solids Total p.p.m. Inf.	Suspended Solids Total p.p.m. Eff.	Suspended Solids Total % Red.	Suspended Solids Volatile p.p.m. Inf.	Suspended Solids Volatile p.p.m. Eff.	Suspended Solids Volatile % Red.	5-day B.O.D. 20° C. p.p.m. Inf.	5-day B.O.D. 20° C. p.p.m. Eff.	5-day B.O.D. 20° C. % Red.	Nitrogen as N Organic + Ammonia p.p.m. Inf.	Nitrogen as N Organic + Ammonia p.p.m. Eff.	Alkalinity as $CaCO_3$ Total p.p.m. Inf.	Alkalinity as $CaCO_3$ Total p.p.m. Eff.	Alkalinity as $CaCO_3$ Phenolphthalein p.p.m. Inf.	Alkalinity as $CaCO_3$ Phenolphthalein p.p.m. Eff.	pH Inf.	pH Eff.
	Set No. 1—1937																					
S	12–12	.635	12.84	4,370	3,090	776	127	83.6	384	63	83.6	340	117	65.6	51	30	870	318	820	270	11.4	11.2
M	12–13	.805	10.14	4,880	2,840	1,358	109	91.9	774	62	92.0	395	165	58.2	90	41	970	548	922	510	11.5	11.3
T	12–7	.794	10.28	3,490	2,640	828	172	79.2	356	59	83.5	255	130	49.0	54	32	405	326	362	260	11.3	11.3
W	12–8	.756	10.80	3,370	2,830	758	95	87.5	382	46	88.0	310	95	72.5	34	19	413	383	366	343	11.3	11.3
T	12–2	.673	12.14	3,700	2,715	777	151	80.5	437	76	82.6	940	300	68.1	97	37	407	459	365	418	11.2	11.2
F	12–3	.644	12.70	4,123	3,257	904	154	83.0	406	56	86.1	380	160	57.9	70	45	404	439	353	389	11.2	11.2
S	12–4	.575	14.20	3,040	3,260	676	220	67.4	328	103	68.6	380	130	65.8	53	38	232	565	182	485	10.9	11.4
Total		4.882																				
Average*		.697	11.80	3,875	2,908	883	144	83.7	447	65	85.5	423	156	63.1	64	34	540	431	493	379	11.3	11.3
	Set No. 2—1938																					
S	11–6	.526	15.52	7,973	5,348	1,428	113	92.0	768	63	91.8	—	—	—	140	94	1,188	636	972	471	11.7	11.4
M	11–7	.971	8.40	3,743	4,035	798	101	87.4	472	64	86.5	—	—	—	114	86	258	888	146	677	9.3	10.6
T	11–1	.911	8.96	5,673	4,247	1,100	100	90.9	600	55	90.9	—	—	—	143	87	1,282	883	1,180	801	11.3	11.2
W	11–2	.916	8.92	5,627	3,924	1,098	139	78.2	360	71	80.3	—	—	—	137	100	920	916	792	795	11.4	11.6
T	11–3	.876	9.32	4,750	3,576	936	102	89.0	520	58	88.9	—	—	—	145	97	138	327	34	231	8.3	10.5
F	11–4	.908	9.00	5,117	4,029	952	106	88.8	552	66	88.0	—	—	—	142	90	344	177	224	86	10.2	9.0
S	11–5	.871	9.36	6,037	4,351	1,050	150	85.7	610	85	86.1	—	—	—	139	103	232	477	155	373	9.6	10.1
Total		5.979																				
Average*		.854	9.56	5,345	4,152	1,026	116	88.7	569	66	88.4	—	—	—	137	94	589	619	472	496	10.2	10.6
	Set No. 3—1939																					
M	5–15	.882	9.26	5,130	4,710	1,054	152	85.5	506	78	84.5	305	163	46.5	125	78	—	—	—	—	12.3	12.3
T	5–16	.887	9.20	4,610	4,150	1,042	171	83.4	494	68	86.2	364	240	34.1	127	98	—	—	—	—	11.5	12.0
Total		1.769																				
Average*		.885	9.23	4,870	4,429	1,050	162	84.6	500	73	85.4	335	202	39.7	126	88	—	—	—	—	11.9	12.1

* Weighted Average.

NOTE: Chlorine demand of effluent—5–15–39, 61.3 p.p.m.; 5–16–39, 55.4 p.p.m.

linity, pH, total and organic nitrogen and chlorine demand were determined on the wastes prior to entering the Dorr tanks and on the effluent from these tanks.

Total solids were determined in Sets No. 1 and 3 by evaporating 100 c.c. to dryness at 103° C. In Set No. 2, the samples were filtered and 100 c.c. evaporated to dryness at 103° C. and the soluble solids therefore determined. To these were added the total suspended solids to obtain the total solids in the sample.

Total and volatile suspended solids, alkalinities, total and organic nitrogen and chlorine demands were determined as outlined in "Standard Methods of Water Analysis," Eighth Edition, 1936, of the American Public Health Association.

The B.O.D.'s were also determined as in "Standard Methods of Water Analysis" except that seeded dilution water was used. The pH of the diluted samples was determined and was found to be between 7.0 and 7.8.

The pH was determined colorimetrically by the use of the Taylor comparator, on the supernatant or filtered samples as the case required.

It should be noted that whenever the pH was between 11.0 and 12.6 the indicator used was Parazo Orange, recommended for use in the presence of lime.

Discussion of Analyses.—In Table IV are shown the results of analyses of the 24-hour composite samples, together with weighted averages for each set.

In passage through the Dorr tanks the total solids in Set No. 1 were reduced from 3,875 p.p.m. to 2,908 p.p.m.; in Set No. 2 from 5,345 to 4,152 and in Set No. 3 from 4,870 to 4,429 p.p.m. It will be noted that in two cases the effluent samples contained more total solids than the influent. In both of these cases it appears that these erroneous results were probably due to sampling as the ratios of lb. per day by analysis to lb. per day by calculation for both of these days were subnormal, being 0.59 and 0.61, respectively (see Table III). Likewise, the ratios for the suspended solids and nitrogen were low.

In the case of tannery waste the best criterion of the treatment process is based on the suspended solids removal. It will be noted (Table IV) that these removals are very good. The weighted averages for Set No. 1 showed 883 p.p.m. in the influent which was reduced to 144 p.p.m. in the effluent or a reduction of 83.7 per cent. In Set No. 2, the reduction was 88.7 per cent. The influent contained 1,026 p.p.m. suspended solids and the effluent 116 p.p.m. An 84.6 per cent reduction was the average of the two results in Set No. 3.

The 5-day biochemical oxygen demand (B.O.D.) of the tannery waste was low, being 423 p.p.m. in the first set and 335 p.p.m. for the third set. In Set No. 1, the effluent contained 156 p.p.m., and in Set No. 3,202 p.p.m. or reductions of 63.1 and 39.7 per cent respectively.

To verify the low B.O.D. results, following Set No. 1, a composite sample of the influent and effluent was collected during the day on

February 15, 1938. The 5-day B.O.D. of the influent was 175 p.p.m. of the effluent 68 p.p.m. or a reduction of 66.9 per cent.

No B.O.D. values are shown for Set 2, since they were not determined as in Sets 1 and 3. In Set 2, tannery wastes were mixed with Waukegan raw sewage in the proportions of volume of tannery waste to the volume of Waukegan sewage. These data indicated that the B.O.D.'s were lower than would normally be expected for tannery wastes. Further work on B.O.D.'s was carried out and is reported in a special section of this paper.

There was one abnormal B.O.D., namely, that obtained on December 2, 1937, in the influent. As four to five dilutions were made in duplicate on each sample, and as these checked, it was decided that there was apparently something unusual in that sample which was not present in our other samples which caused the high value.

There appears to be no relation between the total nitrogen and B.O.D. values. We would expect a lower B.O.D. in the case of Set 1 than in Set 3 due to the fact that the nitrogen values were lower. However, if we discard the high B.O.D. value in Set No. 1, we find that the B.O.D. in the influent samples in Set No. 1 approach closely the values in Set No. 3, which would lead us to assume that the nitrogen values in Set No. 1 are too low, or conversely, the nitrogen values in Set No. 3 are too high. But the nitrogen values in Set 3 were expected to be high, as indicated by the analyses, due to the use in the tannery processes of large quantities of inorganic ammonium salts which do not increase the B.O.D. of the waste, thus these B.O.D. and nitrogen values do not conflict.

Organic nitrogen was also determined on Sets 2 and 3 and was found to be around 40 per cent of the total. The ammonia nitrogen thus by difference being 60 per cent.

The data in Table IV show that there is free lime in both the influent and effluent samples. The average caustic and carbonate alkalinities are tabulated below, results expressed in parts per million.

	Set No. 1		Set No. 2	
	Influent	Effluent	Influent	Effluent
OH (as Ca CO_3)	446	327	355	373
CO_3 (as Ca CO_3)	94	104	234	246
Per cent OH (as Ca CO_3)	82.5	76.4	59.3	60.2

These results indicate that if the dissolved lime in the influent is low then the undissolved lime will continue to dissolve in the settling tanks and that the effluent will actually show an increase in causticity.

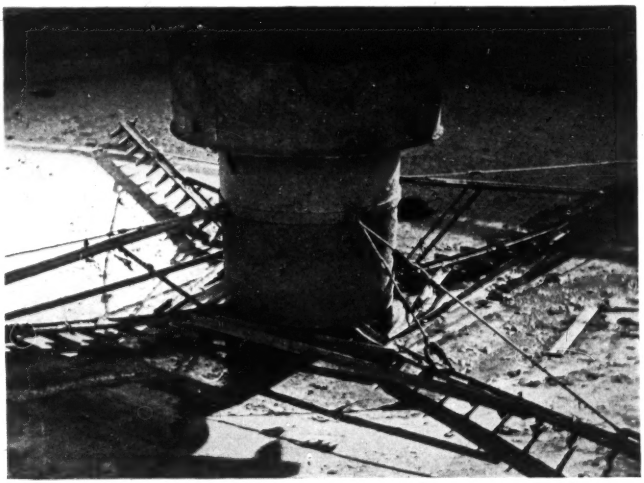
The high removals in suspended solids and B.O.D. indicate that no further advantage could be gained by re-settling the effluent in the Imhoff tanks of the sewage treatment plant. The settling periods in the

Dorr tanks, ranging from 8.4 to 15.5 hours, are evidently quite ample for thorough clarification.

The analyses also showed that the Dorr tanks at the tannery were operating satisfactorily, except during Set No. 1, when it was observed that the sludge being pumped from the Dorr tanks was very thin. This led to a separate study of the operation of these tanks.

Sludge Disposal

Prior to November 2, 1938, it was the practice to pump sludge continuously 12 hours per day from each tank. This resulted in a thin sludge and the pumping of excessive volumes to the sludge lagoons,



Inside view of empty Dorr tank showing sludge scraper and sludge well.

most of which seeped back into the waste disposal system and had to be repumped. This was first called to the Griess-Pfleger Tanning Company's attention when the North Shore Sanitary District analyzed the sludge samples taken with Set No. 1. Dr. Mohlman suggested that a residual of concentrated sludge be left in the tanks and that the sludge be removed periodically down to this residual level. The tanks were thereupon operated experimentally by the laboratory for six months.

During this period a rational schedule of operation was developed. It was found that even at maximum tannery production there was sufficient sludge storage capacity in the tanks for several days accumulation and that the accumulation did not interfere with the efficiency of waste treatment. During this period of thickening, sludge did not tend to harden but if excessive amounts accumulated it became too

thick to flow by gravity as rapidly through the sludge discharge pipe as it was delivered by the pumps. This sort of sludge was found by analysis to contain 7.9 per cent suspended solids. To allow sufficient provision against unexpected shutdowns or unusual conditions, a sludge one-half this concentration, or 4 per cent suspended solids, was adopted as a standard, which is four or five times as concentrated as the sludge previously pumped. This sludge is easily handled and has given no difficulty during a year of operation.

It was further found that the amount of sludge to be pumped could be forecast from a study of the tannery production schedule. This system has been followed for over a year with extremely satisfactory results. At present sludge is pumped on four days per week: Monday, Wednesday, Friday and Saturday. The pumping time for each day is calculated from the formula

$$\frac{[.03\,P_1 + .01\,P_2 + .3\,P_3 + .5\,P_4 + .01\,P_5 + .1\,P_6 + .05\,P_7]}{.25} + 3 = \text{hours}$$

P = packs through the given operation since sludge was last pumped, including expected production for the current day.
P_1 = packs in soak
P_2 = packs out of soak
etc., as in previous equations.

It is not necessary to recalculate the pumping time daily because the same production schedule may be followed for months at a time. During such times, all that is necessary is to correct for holidays and temporary changes in the production schedule. This equation gives the combined pumping time for the two tanks, so if both are in operation and the influent is equally divided between them, each tank will be pumped one half of the time indicated by the equation.

The relationship between production and the amount of suspended solids removed as sludge from the Dorr tanks was determined during the experimental operation of the tanks. During a period of 102 days, November 2, 1938 through February 11, 1939, all sludge removed from the tanks was metered and daily composites analyzed for total and soluble solids and the suspended solids computed. During this period the tannery production was 1,842 packs and 956,377 pounds of dry suspended solids were removed in sludge which gave a relationship of 519.2 pounds per pack. This figure is in close agreement with the result of 521 pounds per pack obtained during the week of February 5 through February 11, 1939.

Table V shows the sludge data for sets 1 and 2 along with the data for the week of February 5 through February 11, 1939 which are typical for the new system of operation.

During the time of Set 1, both tanks were operated by the old method, pumping sludge 12 hours per day, every day. During the time of Set 2, the south tank was still being operated by the old method, but the north tank was being pumped only as sludge accumulated. During the week of February 5 through February 11 both tanks were

TABLE V.—*Sludge Analysis*

Due to continued presence of undissolved lime, sludge is always highly alkaline 500–1000 p.p.m.
Total alkalinity as $CaCO_3$ with a pH of over 11.0. Individual values not shown.

	Set 1			Set 2						Feb. 5 through Feb. 11, 1939		
Production %	43			93						93		
Packs per week	58			125						126		
	Both Tanks			North Tank 55% of influent			South Tank 45% of influent			Both Tanks		
	Gal.	Susp. Solids %	Susp. Solids lb.	Gal.	Susp. Solids %	Susp. Solids lb.	Gal.	Susp. Solids %	Susp. Solids lb.	Gal.	Susp. Solids %	Susp. Solids lb.
Sunday	115,200	2.23	21,438	14,400	4.11	4,807	52,800	.77	3,393	0	0	0
Monday	115,200	.62	5,960	22,800	3.45	6,659	57,600	.93	4,470	57,600	4.65	22,351
Tuesday	115,200	.79	7,595	14,400	2.47	3,004	57,600	1.89	9,133	30,000	3.20	8,011
Wednesday	115,200	1.32	12,497	22,800	2.48	4,757	57,600	.94	4,517	30,000	3.85	9,638
Thursday	115,200	.60	5,768	12,000	3.08	3,104	57,600	.86	4,134	30,000	4.00	10,014
Friday	115,200	.56	5,384	15,600	4.31	5,598	57,600	.99	4,759	30,000	3.75	9,388
Saturday	115,200	.09	894	4,800	4.11	1,642	57,600	1.41	6,729	30,000	4.10	10,264
Total	806,400		59,536	106,800		29,571	398,400		37,135	207,600		65,666
Weighted Average		.89			3.32			1.10			3.79	
Gal. and lb. per pack	13,903		1,026	1,548		429	7,114		663	1,648		521

being pumped by an early variant of the above formula (packs per week $\times$ .347 = total pumping time per week) and here spread over six days of the week, not pumping on Sunday. In this case the total pumping time for the week was 43.7 hours.

Using the current formula and pumping four days per week, the total pumping time for the same production would be 43.6 hours, thus obtaining almost exactly the same concentration of solids in the sludge.

The 1,026 lb. suspended solids per pack calculated for Set 1, is excessively high. It will be recalled that the days in this set are not in a continuous week. The data shows that more than normal amounts of suspended solids were removed on two days, Sunday and Thursday, which considerably overbalance the subnormal amount removed on Saturday. It will also be recalled that more suspended solds per pack were going into the tanks at this time.

In the early stages of the experimental operation of the tanks a great deal of difficulty was encountered from stoppage of the inlet to the sludge well by hair and fleshings. Keeping the sludge thick eliminated part of the difficulty as the heavy sludge disperses and carries the hair much better than a thin sludge. However, there was a persistent tendency for hair to collect on the scraper blades and arms and if not removed in time it would form a mat around the opening to the sludge well and even become heavy enough to stop the scraper mechanism. This difficulty was finally overcome by installing three high pressure water jets in each tank, and washing the blades as they rotate past these jets at the end of each day's pumping. This satisfactorily removes the hair without diluting the sludge or increasing the suspended solids in the effluent from the tanks.

Special Discussion and Comments

Biochemical Oxygen Demand of Tannery Wastes.—It had been expected that the B.O.D. of these wastes would be very high, based on past experience with other tannery wastes. When the results of Set No. 1 all showed B.O.D.'s approximating those obtained from domestic sewage, a study was made to determine the reason for these low results.

A study was made to find out whether there was something in the tannery sewage which might be inhibiting the B.O.D. The high alkalinities were not the cause since the pH on the diluted samples was determined and ranged between 7.0 and 7.8. There appeared to be only two materials in use in the tannery that were not common to all tanneries. One was paranitrophenol, which was used in very small quantities (30 lb. per day) to prevent mould on leather. About 2.0 p.p.m. were found in the waste effluent.

Samples were run containing raw sewage and raw sewage plus 2, 5, 10 and 20 p.p.m. of paranitrophenol. Practically the same results were obtained in all cases, proving that paranitrophenol did not inhibit B.O.D.

The other uncommon material was dimethylamine. Since it was

known that sulfides cause high B.O.D.'s, but that in this tannery sulfides were completely replaced by dimethylamine, it seemed possible that this might be the cause of the low B.O.D. values. Inasmuch as determinations by different investigators were in agreement, it was concluded that the B.O.D. values were correct but that they appear low because of the use of dimethylamine in place of sulfides as unhairing accelerators.

This conclusion is given weight by data in Table I. The B.O.D. determinations made prior to April 24, 1930 were made while sulfides were still being used. Those made in 1936 were made after the change to dimethylamine occurred but while very small amounts of sulfides were still being used.

To verify this conclusion, laboratory unhairing experiments were run with lime alone, with lime and dimethylamine and with lime and sodium sulfide. The results are shown in Table VI.

TABLE VI.—*Laboratory Unhairing Experiments*

250 grams hide to 1000 ml. liquor; hide in contact with liquor 96 hrs. at 75–80° F.

Sample	Per Cent of Hide Weight		Na_2S(60%)	Analysis of Liquor at end of 96 hr.	
	CaO(90%)	Dimethylamine		Per Cent Na_2S	B.O.D.
3–1L.....	10	0	0	0	4500
3–2L.....	10	0.4	0	0	3950
3–3L.....	10	0.6	0	0	4700
3–11L.....	10	0	0.75	0.032	5400
3–12L.....	10	0	1.50	0.098	6500

B.O.D. of Dimethylamine Lime Liquor from Tannery	No. 1	3550
	No. 2	4840
	No. 3	3600
	No. 4	3240

The B.O.D.'s for these experiments were determined by using distilled water containing 300 p.p.m. of sodium bicarbonate, which was seeded with 1.0 per cent of raw sewage from the Waukegan sewage plant. A 0.2 per cent dilution of the lime liquor was made up using this dilution water and it was found that the pH was 9.4 which was too high for determining a B.O.D. 100 ml. of lime liquor sample was then neutralized to a pH of approximately 8.4, using concentrated hydrochloric acid. The diluted samples then had a pH of between 7.5 and 7.8.

The above data indicate that the laboratory dimethylamine liquors gave B.O.D.'s of the same order of magnitude as the tannery liquors, that dimethylamine does not increase the B.O.D. of an unhairing liquor, and that sodium sulfide does increase the B.O.D. of an unhairing liquor.

There still remains the possibility that chromium salts may have inhibited the B.O.D. results, since Monk [2, 3] has shown that chromium salts, if soluble, are toxic to biological sewage treatment processes when present between 3.5 and 67 p.p.m. of chromium. Other tests with *B. Aerogenes* showed that 50 p.p.m. of CrO_3 were toxic. Previous work

by Strell [4] showed that a dilution greater than 1 to 25,000 of chrome salts was necessary to maintain biological action.

However, there should be very little, if any, soluble chromium in these very alkaline wastes. Further work is required to determine the influence, if any, of chromium.

Suspended Solids of Tannery Waste.—The character of the tannery effluent led us to suspect that the standard method for determining suspended solids might give high results. This method calls for filtration, with a Gooch crucible and a 2–3 mm. asbestos mat, of an amount of sample giving less than 30 mg. of residue. In the case of tannery wastes, especially Dorr tank effluent samples, the suspended solids are low in comparison with the soluble solids. This causes high suspended solids results due to the retention of soluble solids in the asbestos which are later weighed and included in the suspended solids.

Washing the filter and suspended solids (especially influent samples) dissolves some of the lime and causes low results. It was found to be desirable to carefully standardize the amount of asbestos used in preparing the filter, and subtract from each determination a blank run by using the filtrate to thoroughly wet the asbestos, applying suction for a few minutes, then drying and weighing as usual.

This method was found to give more consistent results and at the same time it eliminates an error which may be considerable for tannery wastes.

From the results we obtained we believe that those reported in this paper using the standard method, are somewhat high.

Chemical Precipitation.—The possibility of improving the removal of suspended solids by chemical precipitation was investigated. Due to the high alkalinity of the influent, ferrisul appeared to be a likely chemical to try. A two day run using a dosage of 20 to 25 p.p.m. was made. The results are shown in Table VII.

TABLE VII.—*Chemical Precipitation of Suspended Solids by Ferrisul*

Dosage 20–25 parts per million

Date	Influent M.G.D.		Effluent Suspended Solids, p.p.m.		Chemical Treatment
	North Tank	South Tank	North Tank	South Tank	Ferrisul, p.p.m.
11–2–37	.359	.294	97	75	0
11–3–37	.369	.302	40	16	20–25
11–4–37	.442	.362	57	33	20–25
11–5–37	.340	.278	137	94	0

The data indicate that, at the relatively low flows shown, chemical precipitation by ferrisul would decrease the suspended solids in the effluent by more than 50 per cent. At high flows, which might be as much as double those shown, the removals would probably be somewhat less.

The ferrisul was added at the pump intake in the collecting sump because it was expected that the flow through the pump and the 570-ft. pipe to the settling tanks would completely mix the chemical solution in the waste influent.

Scum Prevention.—From time to time large amounts of scum had been observed to collect on the surface of the Dorr tanks. If this were not removed, the layer would become thick enough to extend below the tank rim baffle, it would then slough off from the bottom of the layer and be carried away by the effluent. At one time the scum formation was so great that it required the constant attention of a workman to keep it removed.

A comparison of samples taken from the collecting sump with those taken from the dividing chamber at the Dorr tank disclosed an interesting difference. The suspended solids in the samples from the sump flocculated readily and rapidly settled to the bottom, while those in the samples taken at the dividing chamber flocculated readily but instead of settling to the bottom, rose to the top and in many cases remained there permanently. This led to a systematic investigation. Throughout a working day, periodic samples were taken at the sump and at corresponding times at the dividing chamber (2½ minutes was found to be the time of travel through the 570-ft. pipe). This investigation disclosed that when the inlet to the pump was under water, the suspended solids in the samples taken at the settling tank settled to the bottom normally but if the inlet to the pump was partially exposed, so that air was sucked in with the waste, the suspended solids would not settle down but became so intimately mixed with air that they rose to the top and the retention of air was sufficient to hold them there.

The problem was solved by installing a float control so that the pump was automatically shut off before the waste level in the sump fell low enough to expose the pump intake.

Summary

(1) A joint investigation was made by the Griess-Pfleger Tanning Co. and the North Shore Sanitary District of the characteristics of the tannery waste to determine whether further treatment at the Waukegan sewage treatment works was necessary.

(2) The tannery waste, 0.5 to 1.25 m.g.d., is divided between and passed through two 170,000 Dorr settling tanks at the tannery.

(3) A total of 2088 Dorr tank influent, effluent and sludge samples were collected in three sets; 7 days in December, 1937
7 days in November, 1938
2 days in May, 1939
These samples were composited, proportional to flow, for 24-hour periods and various shorter periods. The sampling and analytical methods are described.

(4) Analytical results of the 24-hour composite samples for total and suspended solids, organic and ammonia nitrogen, total and phe-

nolphthalein alkalinity and B.O.D. are shown along with previous analytical data collected over a period of 20 years.

(5) The relationship between production and volume of waste and distribution by days and hours is shown.

(6) The inherent variations in departmental production from one day to another are described and equations are given for calculating the weighted production of the various departments in relation to waste, and the amounts of various components that may be expected to be found in the wastes. These values are compared with those determined by analysis.

(7) The weights of the various components per pack (4200 lb. green salted trimmed weight) processed are given and process changes are shown to affect these relationships.

(8) The general tannery processes are described and factors affecting the tannery waste, that are peculiar to this tannery, are discussed.

1. Dilution by seepage water.
2. The use of dimethylamine in place of sulfides as sharpening agents in lime liquors and the resultant effect on B.O.D.

(9) The waste disposal equipment is described.

(10) The removal and disposal of sludge from the Dorr tanks is discussed.

(11) The prevention of scum on the surface of the Dorr tanks is described.

(12) The efficiency of the Dorr tank treatment is shown by the 50 per cent reduction in B.O.D. and the 85 per cent reduction in suspended solids but the possibility of increasing this efficiency by chemical treatment is mentioned.

(13) The conclusion is drawn that the present efficiency of the Dorr tanks is sufficient and as great as could be expected from a primary treatment and that inasmuch as the Waukegan sewage treatment plant is one of primary treatment only, further treatment of these wastes at the Waukegan sewage treatment plant is not necessary.

Acknowledgments

The authors wish to express their appreciation to Mr. J. H. Jordan, Vice President and Manager, and the other officers and personnel of the Griess-Pfleger Tanning Company, and to Mr. John Oliver, President and Mr. F. M. West, Trustee for Waukegan and to the other trustees and personnel of the North Shore Sanitary District for their cooperation.

They also wish to thank the State of Illinois Sanitary Water Board for their cooperation and particularly Mr. C. W. Klassen, Technical Secretary, for permission to use their analyses of the Griess-Pfleger Tanning Company waste and Mr. H. H. Black, Assistant Sanitary Engineer, for his suggestions during the course of these investigations, following his survey of the tannery wastes in 1936.

The authors feel that the encouragement and criticism of Dr. F. W. Mohlman has been of great assistance to them in this work and are very grateful for his help.

BIBLIOGRAPHY

1. H. Gladys Swope, "Chemical Treatment at Waukegan, Illinois." THIS JOURNAL, **11**, 93–99 (1939).
2. H. E. Monk and J. H. Spencer, "Some Chemical and Bacteriological Properties of Trade Wastes containing Chromium. Treatment of Chromium Plating Wastes." *Sewage Purification* **1**, 364, 356 (August 1939). Abs., THIS JOURNAL, **11**, 920–21 (1939).
3. H. E. Monk, "Some Chemical and Bacteriological Properties of Trade Wastes containing Chromates." *The Surveyor*, **96**, 69–71 (1939). Abs., THIS JOURNAL, **11**, 1099–1100 (1939).
4. Strell, "Tannery Waste Treatment." *Stadtereinigung*, **27**, 357 and 379 (1935). *Eng. News-Rec.*, **116**, 288 (February 20, 1936).

Operators' Reports and Suggestions

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SEWAGE WORKS RECORDS *

By P. J. Kleiser

Engineer, Indiana State Board of Health

An important factor in the successful operation of a sewage treatment plant is plant records. A sewage treatment plant is an installation designed and constructed by mortal man for the sole purpose of bringing about nature's changes as rapidly as possible with minimum amount of difficulty, with the idea definitely in mind to prevent the pollution of some watercourse. Good sewage plant operation implies that each unit of the plant is controlled in such a manner that it performs its specific duty with the highest possible efficiency. A treatment plant, like any other business, must be run on a business-like basis and accordingly must receive such daily attention as will guarantee that it will accomplish the purpose for which it was constructed.

Successful operation is dependent upon adequate records, operation records which will give an authentic picture of what each unit of the plant is doing. This is necessary in order to eliminate the possibility of one unit upsetting other functional parts of the plant. By this frequent cross-observation of the units it may be possible for you to demonstrate to your superiors by adequate records that a certain unit is not performing according to the original intent of design. These recorded facts will give you concrete evidence to justify your request to repair or replace the unit not functioning properly. While no doubt your integrity is never questioned, it would be difficult to convince your council or governing board by merely reporting that a screenings grinder or sludge collecting mechanism needed immediate attention. Ordinarily such boards are hardest to convince and your *interests* are protected by having the necessary facts to substantiate your claim.

Good records are of invaluable service when law suits develop regarding stream pollution or odor nuisances. In this respect let us quote from a recent *The San Joaquin Bulletin,* Stockton, California:

> A certain plant consisting of an Imhoff tank, trickling filter, secondary settling, sand filter units and pre and post chlorination discharged the final effluent to a stream. Two cases of typhoid fever developed in residents downstream who had been swimming in the creek. A careful investigation of the records (rather complete) of the plant led to the conclusion that the plant had been operated with reasonable care during the period under consideration.

* Presented at the Sewage Works Operators' Short Course, Purdue University, March 29, 1940.

The plant operator remarked after the investigation that he now understood the importance of records and the reasons for insistence by the Bureau that *complete* and *accurate* records be kept *up-to-date*.

Keep this in mind. You may have to rely on your own plant records some day. Several years ago in our own state a certain superintendent of one of the larger treatment plants would subject the visitor to a cross-examination regarding any peculiar odors above those normally noted at a separate sludge-digestion, trickling filter type plant. This man was building a defense against a damage suit filed in regard to odors.

Rehabilitation or extensions to a sewage treatment plant could be more thoughtfully planned if proper operation records were available at the plant under consideration for such changes. For instance, it would be entirely possible for an operator to suggest design changes after his records *proved* that the design of certain channels made them difficult to clean; that too much time was spent draining sludge lines after use; that more adequate heating facilities would increase digestion and supply more gas; that ample space be provided to insure elbow room in screen chambers; that underground valves should be placed in manholes; that the plant should have been placed above high water stages in the outlet stream, and possibly many more defective items of equal importance. We must remember that all mis-operation faults do not lie wholly with the operator because he usually must accept a plant designed by an engineer unappreciative of the short cuts so valuable to a plant operator.

Adequate daily records make it possible to submit a monthly report to your superiors and an adequate monthly report is a necessity in the preparation of your annual report. While it is true that the State Board of Health has a regulation requiring the submission of operation sheets, we would not want any of the operators to submit it for that specific reason alone. Rule SE–16 is quoted as follows:

Rule SE–16. Requiring Proper Operation of Sewage Treatment Works and Submission of Reports of Operation.

1. All sewage treatment works shall be properly and efficiently operated under the supervision of a competent operator or superintendent.
2. Monthly reports of operation of sewage treatment works shall be submitted by the owner to the State Board of Health on or before the tenth day of the month following. These reports shall include such items of information as may be specified from time to time by the State Health Commissioner.
3. Provided, that nothing contained in this rule shall apply to sewage treatment works serving a private residence.

It should be of great interest to you to keep these necessary records in order that you can obtain data not only on the efficient operation of various units but the absolute cost of the operation of the various units which is a necessity in any business. The city of Goshen had an experience on costs that is of interest. The water meter testing department repaired meters and estimated the cost to be between $3 and $4

and there was no routine check made of the meters in service even though only 60 per cent of the water was paid for that was pumped. A man was placed on the water works payroll who interested the city in improving their records on this item. The results are that out of 1,100 meters checked, repaired and replaced to date, the average cost was found to be only $1.25 instead of $3 or $4 and the gaging efficiency of these meters changed from 66 to 98 per cent. The obvious result of this procedure meant increased revenues. This is mentioned here because Goshen also pays for sewage treatment by sewer service charge based on flat rate plus water consumption.

The interest in records has reached the point in New York State whereby the sewage works association set up an Association Rating Committee which invites competition from the plant operators to submit copies of their annual reports. These reports contain all the operating and control data required by the rating schedule for the treatment units contained in their respective plants. The winner is the recipient of a silver loving cup. It may be possible in the distant future *or* in the near future for such procedure to be adopted in Indiana. If it would encourage the submission of better operation reports than we have been receiving in many instances, I believe that Mr. Ross should appoint a committee to report at the next annual meeting of the Indiana Sewage Works Association the possibility of having some competitive activity regarding records. At any rate the Secretary of the Sewage Works Association would be glad to solicit a collection to purchase said cup in case the committee makes a report favorable to such an award. For those of you who protest against an operation sheet, the information obtained from New York shows that the data their operators must submit in competion for the award far exceeds the items listed on the sewage operation sheet which we require to be filled out. Our present operation form is to be revised in the near future. It is interesting to note that the operators at small treatment plants, those treating 1, 2 and 3.4 million gallons a day, have won the coveted award. I am sure that it was not the idea of the committee to make work for itself in judging these reports but to create in the operator an incentive to prepare a report, valuable to the operator himself, the municipality, state agencies, and designing engineers.

BIBLIOGRAPHY

Municipal Sanitation, Feb., 1938.
Sewage Works Journal, May, 1939.
Sewage Gas, June, 1939.

GADGET CONTEST, CENTRAL STATES SEWAGE WORKS ASSOCIATION MEETING IN OCTOBER, 1939

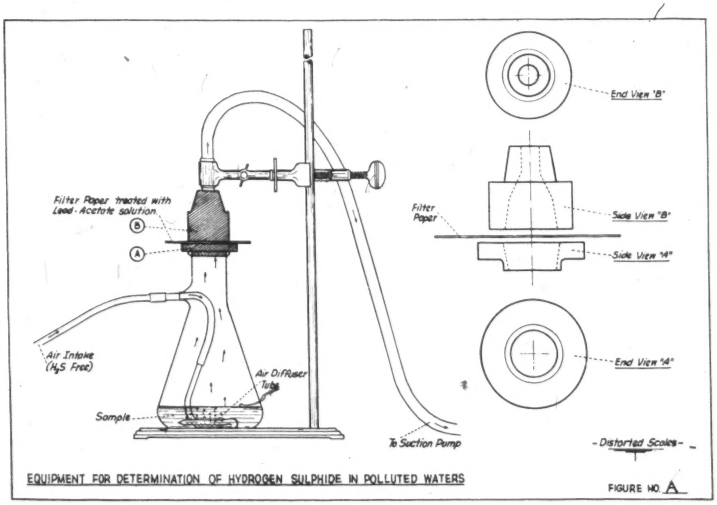
First Prize

By George Martin

Metropolitan Sewerage District, Green Bay, Wisconsin

The Determination of Hydrogen Sulfide in Sewage and Polluted Water

In making routine determinations of hydrogen sulfide in sewage, sewage gas, and polluted waters it was found that the procedure as described in Standard Methods was not satisfactory due to the fact that polluted waters and sewage have an iodine demand. Therefore, a modified or special method of procedure was adopted. This special method is based upon the known fact that filter paper treated with a lead acetate solution will darken when placed in contact with hydrogen sulfide. It was found that by making a set of standards with which any sample might be compared consistent and fairly accurate results could be obtained.



EQUIPMENT FOR DETERMINATION OF HYDROGEN SULPHIDE IN POLLUTED WATERS

FIGURE NO. A

The apparatus necessary for making these determinations consists of a standard 500 ml. filtering flask on the inside of which is placed an air diffuser made of a perforated aluminum tube connected to the flask's

side tube by means of a rubber hose. On the outside of the side tube there is attached the rubber air intake hose. The lead acetate paper is held in place on the top of the suction flask between a rubber ring *"A,"* which is a standard Gooch crucible holder for an ordinary two inch funnel, and a standard Gooch crucible holder *"B,"* as is ordinarily used with a filter flask. *"A"* and *"B"* are held together by a utility clamp fastened to a ring stand. The rubber hose which is attached to the glass tubing of *"B"* is connected to a suction device.

In making a determination with this apparatus the sample to be tested is drawn into the flask directly from a pipette through the aeration tube. Air is then drawn through the liquid for two minutes and by so doing the hydrogen sulfide passes on up through the lead acetate paper, discoloring it. The amount of hydrogen sulfide is determined by comparing the colored lead acetate paper with the standards and converting the results into the desired units.

In order to operate this apparatus satisfactorily it is necessary that there be at least 100 ml. of liquid in the flask. Thus, if the sample being tested is high in hydrogen sulfide, it becomes necessary to dilute it with hydrogen sulfide free water. If it is desired to have the final results in p.p.m., this figure is arrived at by multiplying the color comparison in mg. by 1000 (mg. per liter or p.p.m.) and dividing by the ml. of sample used.

Example: Sample—10 ml.
Volume of water added to flask before sample—90 ml.
Color comparison—0.05

$$\text{p.p.m.} = \frac{0.05 \times 1000}{10} = 5 \text{ p.p.m.}$$

The lead acetate paper is prepared by soaking filter paper in a 10 per cent solution of lead acetate and drying in an oven until approximately 10 to 15 per cent of the moisture remains in the paper. The paper must then be kept in an air-tight container.

Standards are made from a solution of hydrogen sulfide prepared by generating hydrogen sulfide in distilled water from ferric sulfide by the addition of dilute sulfuric acid, the solution being standardized by iodine titration.

Gas may be analyzed for hydrogen sulfide by measuring a known quantity in an Orsat gas measuring tube and then quickly passing the known volume through the above described apparatus. This method gives results in mg. per ml. used.

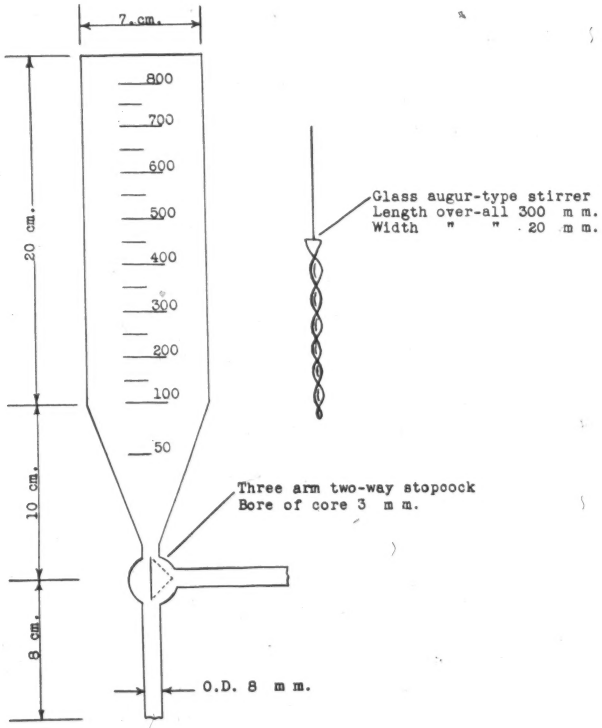
Second Prize

By David Backmeyer and W. E. Ross

Sewage Treatment Works, Richmond, Indiana

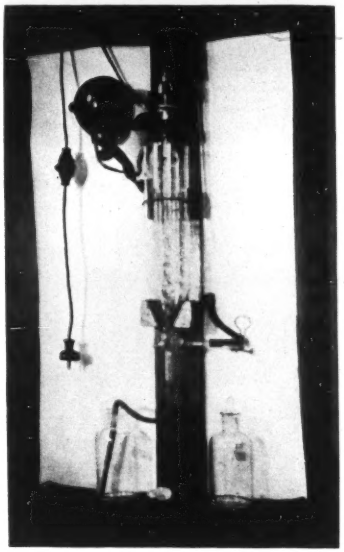
B.O.D. Dilution Dispenser

Operation.—A measured volume of sewage is added from a pipette into the open top of the mixing chamber and dilution water is run in from the bottom (by gravity flow) until the 700 c.c. mark is reached. The total liquid volume is then 690 c.c. (700 c.c. less 10 c.c. displaced by the glass stirrer). The electric driven stirrer is turned on and in ten



seconds the mixture is ready to be drawn into the dissolved oxygen bottles. The rubber tube connected to the bottom of the dispenser permits rapid and efficient filling of the bottles without the entrainment

of air bubbles. The special three-arm two-way stopcock allows the mixing chamber to be filled and emptied with the least possible effort.



The B.O.D. results in p.p.m. are taken from a table which gives the corresponding values for the depletion in dissolved oxygen after the sample has been incubated.

Total cost of gadget as completely assembled $21.00.

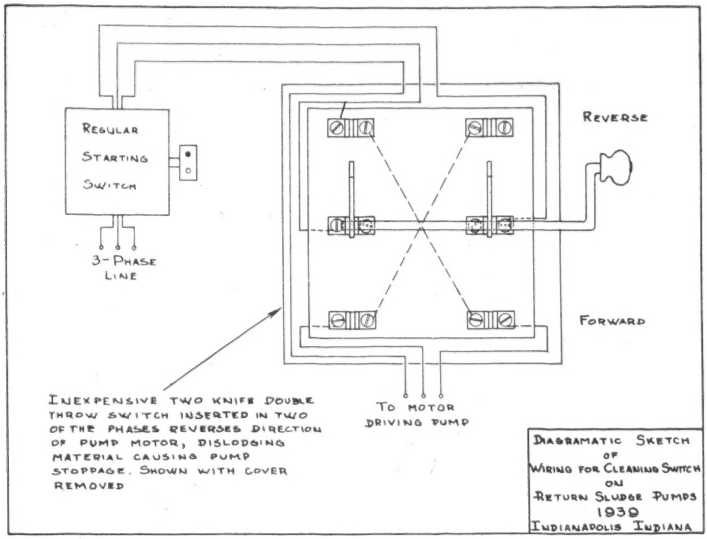
Third Prize

By P. W. Richards

Operating Engineer, Department of Sanitation, Indianapolis, Ind.

Pump Cleaning Gadget

This simple electrical switch inserted in the wiring to a pump motor eliminated the daily removal of the pump head. Each day before the reversing switch was installed, the pump head had to be taken off in order to remove such fine material as small feathers, match sticks, etc., that passed the coarse bar screens and collected on the pump impellers and under the impeller rings. The labor cost in cleaning seven of these pumps per day at Indianapolis was $2.80 or slightly over $1,000 per year.


REGULAR
STARTING
SWITCH
3-PHASE
LINE
REVERSE
FORWARD
INEXPENSIVE TWO KNIFE DOUBLE THROW SWITCH INSERTED IN TWO OF THE PHASES REVERSES DIRECTION OF PUMP MOTOR, DISLODGING MATERIAL CAUSING PUMP STOPPAGE. SHOWN WITH COVER REMOVED
TO MOTOR DRIVING PUMP
DIAGRAMATIC SKETCH OF WIRING FOR CLEANING SWITCH ON RETURN SLUDGE PUMPS 1939 INDIANAPOLIS INDIANA

With the installation of these switches on the pumps, it is only necessary to stop the pump, throw the switch to reverse and run the pump backwards for thirty seconds. This dislodges the clogging matter and when the pump is started forward again, practically all of it will pass the impeller.

It should be remembered that if there are screw-on impeller wearing rings on the impeller they should be fastened, so that in the reversing operation they will not come off.

SEWAGE GAS UTILIZATION SYSTEMS*

By L. L. Langford

Eastern Sales Manager, Pacific Flush Tank Company

Foreword

Since the very few isolated pioneer installations of less than ten years ago, the utilization of sewage sludge gas has become an almost universal practice in sewage treatment plant design. In fact, in many cases the operation of the gas utilization system requires more careful attention to details than does the routine operation of producing a satis-

* Presented at the Spring Meeting of the New England Sewage Works Association, Middletown, Conn., April 16, 1940.

factory effluent, which is the primary function of a sewage treatment plant. It is only natural that with so rapid a development, numerous operating difficulties would be experienced.

A special committee of the New Jersey Sewage Works Association conducted a very comprehensive survey of the hazards involved in gas handling systems.[1] Their report incorporates a set of very excellent rules covering the design and operation of each piece of equipment and part of the system. These rules, together with the suggestions as set forth by a number of prominent authorities in the field of sewage treatment and published subsequently in *Municipal Sanitation* as a panel discussion,[2, 4] has done much to focus attention on the problems involved. With such work as a background, it is the purpose of this paper to present a discussion which will better acquaint designers and operators of sewage treatment plants, with some of the problems involved, so that gas utilization systems may be operated with a minimum of attention and a maximum of safety.

Early History

Probably the first attempt in this country to collect and utilize gas was made by C. C. Hommon at the Peachtree plant in Atlanta, Georgia, where gas vents of the Imhoff tanks were covered and the gas collected and used for heating and cooking.[5] This work was done about 1915. By 1921, concrete covers had been placed over the gas vents of an Imhoff tank at Austin, Texas, and the gas taken off and burned in a small furnace.

In 1924, the Rockville Center, N. Y., plant was designed[6] including a complete gas system, involving the use of a gas engine driven electric generator and a gas engine driven blower unit. This plant, designed by Clyde Potts, included the use of engine jacket water and exhaust gases for heating the separate sludge digestion tanks. The plant was not put into service, however, until 1929, and, in regard to it, the *Engineering News-Record* in 1931 printed the following statement—"Construction of a plant designed by Clyde Potts in 1917 for Jersey City, was prevented by an injunction granted by the Chancery Court. The injunction was based on the novelty of the design which included preliminary settling tanks and sludge digestion, sludge heating and utilization of sludge gases. Those features which were novel in 1917 are now well established in practice and find sound exemplification in the recently completed Rockville Center plant."

In 1925, Dr. Rudolfs, at Plainfield, N. J., conducted some very interesting experiments and published a paper in the N. J. S. W. A. *Proceedings*[8] on the quality and physical characteristics of sewage gas indicating its value as fuel. Following this work by Dr. Rudolfs, John R. Downes, in 1926, operated three gasoline engines on sewage gas, using the power developed in connection with the sewage treatment plant at Plainfield, N. J.[9]

In 1926, at Antigo, Wisconsin,[10] Jerry Donohue installed a heated

separate sludge digestion tank, utilizing the gas produced for maintaining digestion tank temperatures.

In 1928, William Piatt installed gas engines at the Sugar Creek plant in Charlotte, North Carolina, these engines totalling 285 H.P. The gas had previously been used for incineration at this plant. At these and many other installations, there have been worked out many of the difficult operating problems involved in the safe utilization of sewage gas, until to-day, the utilization of sewage gas for power and heat is accepted practice.[11] The large installation at the Tallmans Island Plant in New York City, incorporating eight gas engines with a total of 3500 H.P., indicates that we have come a long way in the use of this by-product of sewage treatment.

The Problem

There are two major hazards encountered in the handling of sewage gas:

(*a*) When mixed with air in certain ratios, sewage gas is highly explosive.

(*b*) Sewage gas is toxic to man.

In any problem of handling sewage gas, we must consider and eliminate these two hazards.

To better understand the problems in handling sewage gas, we might briefly consider its composition. The chemical properties of the gas will depend somewhat upon the characteristics of the sewage sludge being digested and the conditions of digestion. Essentially, it will consist of a mixture of methane and carbon dioxide, with traces of hydrogen and nitrogen. In some cases, hydrogen sulfide, carbon monoxide, oxygen and traces of other gases will be present. The two main constituents are methane and carbon dioxide, which in most cases will make up better than 95 per cent of the gas. It might be interesting to note that the richness of the gas, that is, the percentage of the methane present is quite dependent upon the condition of digestion. In the initial operation of any digestion tank, gas will be produced which may contain as much as 60 or 70 per cent carbon dioxide. Carbon dioxide is produced in the first or acid stage of digestion and a suitable gas for burning will not be produced until the second or alkaline stage of digestion has proceeded sufficiently to increase the methane content of the gas. A normal gas will contain from 60 to 75 per cent of methane. In this regard, William Piatt at Durham, N. C., has developed a CO_2 indicator which gives a continuous record of the CO_2 in the gas, indicating not only the approximate heat value of the gas, but also providing a very good control of the conditions within the digestion tank.

A normal gas containing from 60 to 75 per cent methane will ignite and burn safely if there is no air present in the source of the supply, but if this gas is mixed with from 7 to 14 parts of air, the resulting mixture will be highly explosive. It is possible for explosions to travel in

pipe lines and enclosed chambers for considerable distances until the force of the explosion ruptures the pipe or chamber. The explosions or ignition of gas mixtures in the pipe line occur in increasing intensity—the greater the length of line or size of chamber, the greater the intensity of the explosion. Consequently, it is imperative that we eliminate all sources of a possible gas-air mixture in the gas collection and handling system. If these sources of air mixture are eliminated, we will have greatly reduced the first of the two major hazards previously mentioned.

In this country, the digestion tanks now in operation are essentially of two types, either with fixed covers or with floating covers. Extreme care should be exercised in the operation of the digestion tank itself [20-25] to eliminate the possibility of entraining air. If digestion tanks are operated in such a manner that a positive gas pressure is available within the entire system at all times, the possibility of a mixture of air and gas occurring will be eliminated and the safety of the system will be assured. Inasmuch as the possibility exists of careless or faulty operation, it is necessary to take precautions to isolate, as much as possible, the sources of ignition hazards throughout the system. All possible sources of ignition must be isolated. Such sources of ignition consist of open flames in boilers, unit heaters, incinerators, waste gas burners, pilot lines, laboratory burners and water heaters also backfire from internal combustion engines or any other operating device connected into the gas system which might cause ignition by sparking. The generally accepted methods of isolating sources of ignition is by placing a flame trap in the gas line between the source of supply and the device which presents the ignition hazard. The flame trap should be placed as near to the source of ignition as possible to reduce the increasing intensity of explosion or flash-back in the gas line. If a flame trap were placed in the gas line far enough from the source of supply, it is possible to rupture the flame trap element itself, thereby rendering it useless, due to the intensity of the explosion.

The flame traps generally in use at the present time are of the dry type, operating on the principle of the Davy Miner's Lamp Screen, which allows the gas to pass through but not burn on the unprotected side of the screen. The flame trap elements are designed to allow the explosive or burnable mixture to burn on the ignition side of the element, at the same time providing sufficient radiation surface to lower the temperature on the protected side to a point where the gas will not ignite. No element can be economically designed to withstand the burning temperatures indefinitely, and consequently some device such as a thermal-release, should be provided so that the gas supply will be cut off when a hazardous condition exists. This will protect against element failure due to melting or overheating.

By providing proper flame trap protection at all sources of ignition in the gas handling system, and by maintaining them in good working order, we can be assured that the system will be adequately protected.

In many plants there are in operation flame traps of the waterseal

type. The effectiveness of these traps is dependent upon the full waterseal being present at all times. A reduced seal, or a lowering of operating water level in any trap of this kind, will reduce its effectiveness. In all cases a reduced seal presents a very real hazard as the seal may be blown and allow gas to escape into the surrounding room or chamber, unless such traps have been vented to atmosphere. Water levels should be very carefully and frequently checked.

With respect to the second major hazard, there is always a possibility of gas leaking into the control building, chambers, tunnels or other structures around the plant. A slight leakage of gas will, in a short period of time, when mixed with surrounding air present a very hazardous condition from the standpoint of explosion. If the leakage occurs in sufficient quantity it may present the additional hazard of suffocation.

Extreme care should be exercised in the design of new plants and in the operation of those already completed to provide for adequate ventilation and free access to exits in all structures where a possibility of gas leakage is present.

We should like to call attention to a few features which might be taken into account in the design and operation of sewage plants, and which in the past have caused considerable operating difficulties.

All control devices and the gas handling system as a whole should be of adequate size to assure proper operation under all conditions of gas production and consumption, within gas pressures which are available. Most of the gas utilization systems in service today are operating with a normal pressure at the digestion tank of about 6 in. of water. When operating with such comparatively low pressures, it is necessary that all parts of the system be designed to produce a minimum of loss. Studies of pressure losses in sewage gas systems indicate that in some cases losses are considerably in excess of what might be expected in using present accepted formulas for gas flow in pipes. This is possibly due to the fact that sewage gas quite often contains minute solid impurities in suspension. Systems in service have indicated considerable deposits in pipe lines. As the production of gas will follow closely the additions of raw solids, it is therefore to be expected that considerable variations in gas production are to be anticipated and the gas system should be adequate to handle maximum hourly production.

As collected, gas will be approximately at the same temperature as the digestion tank, which, if heated, will probably be from 80 to 90 degrees. This gas will contain moisture, in some cases approaching the saturation point. As the gas is taken from the tanks, the pipe lines may pass through cold ground or cooler buildings, in which case the moisture in the gas will condense out in the lines. It is imperative that drainage be provided so that this moisture can be removed. The usual practice is to slope all lines to a minimum number of low points and at such points provide means for removing the condensate. Condensate traps may be provided for manual operation and should be designed so that the possibility of leakage of gas at these points is eliminated.

The gas utilization systems which have been installed in the smaller treatment plants, serving as few as 1,000 people or less, present considerably different operating problems than do the systems of the larger and more complex plants. There is, however, one consideration which is common to all gas utilization systems, the gas being produced must be utilized or disposed of without nuisance. The intensity of the odor of sewage gas will vary somewhat with the constituents in the gas, particularly if hydrogen sulfide is present. All sewage gas does, however, have a characteristic odor and can present a nuisance problem if not utilized or burned. If the consuming devices, such as boilers or gas engines, are out of service, or if the production of gas exceeds the required consumption, provision must be made to dispose of the gas automatically. The simplest method of such disposition of excess gas is to provide an automatic pressure relief to allow the gas to flow to a waste burner. The burner should have a pilot flame constantly burning to assure ignition of the main burner. The pressure relief should be of the sensitive, weighted diaphragm type which may be adjusted within close limits to open at a pre-determined pressure. Such pressure may be set at a point above that pressure in the system at which the normal consuming devices will operate at full input. Thus, in a simple gas system including a gas boiler for digester and building heating, the boiler will generally operate on a maximum pressure of about 3 in. of water. Allowing about 1 in. for loss in the flame trap, gas meters and lines, the pressure relief may be set at 4 in. or 4½ in. of water, and the excess gas will automatically waste when the production exceeds the boiler capacity or when the boiler is out of service.

This same principle of operation will also apply in the more complex systems, where a multiplicity of consuming units are in service. In case all normal consuming devices are out of service the total gas production must be considered as excess gas. Provision should be made in every plant to dispose of this excess gas without nuisance. The term "without nuisance" may be given a broad interpretation, however, and if the plant is small and completely isolated it may be that excess gas might be wasted to atmosphere without burning, and without presenting a nuisance problem. Whether excess gas is wasted to atmosphere without burning, or consumed in a waste burner, the point of waste must be considered as an open flame and adequate flame trap protection should be provided. Pilot lines for waste burners should always be connected to a protected service line or provided with individual flame trap protection.

In most smaller plants the gas-fired, hot water boiler may be considered as the heart of the gas system. If the boiler operates without trouble it is, in most cases, given very little attention. It is, however, a point of hazard and should be watched carefully. In most cases, such boilers are of the multiple burner type equipped with multiple pilots and what might be termed standard boiler trim.[35, 36] Such trim includes, among other controls, a gas pressure regulator and thermapilot controlling a gas shut-off valve. This control is very important

and should be periodically checked to be certain that it is in proper operating condition. The purpose of the control is to insure that if the pilot ceases to burn, the main gas supply will be cut off. Should the pilot fail and the main gas supply not be cut off, the gas might fill the boiler room. This is most likely to happen during summer operation when the demand for heat is at a minimum and the boiler is frequently cut in and out of service by the thermostatic control. In addition to the gas shut-off valve, other boiler controls, particularly the thermal pilot should be checked periodically to determine that they are functioning properly. In cases where the boiler trim and the controls are complicated, servicing can preferably be done by a competent boiler serviceman.

Another operating consideration which should be given attention with respect to the installation and operation of gas boilers has to do with the boiler room itself. This should be well ventilated and sufficiently large to insure an ample supply of oxygen to be present at all times. A boiler installed in a small, unventilated chamber is very hazardous in that the boiler may deplete the supply of oxygen available to such a point that it will no longer burn. If forced ventilation is to be installed, however, care should be exercised to be certain that the forced draft does not affect the normal draft of the boiler flue.

In practically all plants where the sole use of gas is for heating, it is possible to consume in the boiler all of the gas produced, or sufficient gas to take care of all heating requirements without recourse to any gas storage. The boiler capacity is sufficiently flexible to take up the normal fluctuations in gas production, but when gas engines are installed, however, consideration must be given to balancing the most economical size of engine and the program of operation with the gas supply available. The amount of gas storage will depend upon the size and number of gas engines, the capacity of other units of gas consumption, the proposed schedule of operation, and the percentage of total gas production that is to be used. It is obvious that more gas storage will be required to operate engines designed to consume the entire day's gas production during the peak demand period of say 6 to 8 hours, than would be the case for a smaller engine installation operating continuously throughout the day. The quantity of gas storage provided as an integral portion of a power production plant must be included in the study of individual units and justified in cost as an appurtenance of the system.

The type of gas storage must also be determined on the basis of a study of costs. Pressure storage in either the cylindrical "bullet" holder or spherical type holder, together with compressors, and auxiliary controls, and the cost of the operation of the compressors to store the excess gas, may be compared to the gravity type holder of either the waterseal or piston type. Each type of storage has its limitations and its application and each has been satisfactorily adapted to plants now in operation.

The larger the plant and the more numerous and varied the uses of gas, the more complicated becomes the control system. From the

standpoint of the operator, it is important to know just what is happening throughout the system for he must be able to find the troubles as they develop and remedy them before they become effective. Essentially there are two things that the operator needs to know, to determine whether any part of the gas system is functioning properly. They are—(1) the quantity of gas being handled, and (2) the pressure, or what is more to the point, the pressure drop through any particular device in question. In determining the quantity of gas, it is always desirable to be able to determine first the amount of gas being produced. Likewise, the record of gas production from each digestion tank will give a very good indication as to whether the tank is functioning properly. A drop in gas production will give the operator a warning that he should check and see whether the solid loading has been reduced, or if not, what other conditions have varied in the operation of his tank permitting him to take corrective measures. It is, therefore, quite important to be able to check the operation of the digestion tanks by metering the gas from each unit. While in smaller plants this may be the only record required, a metering of the gas burned in the boiler will, by subtracting from the total production, give the quantity of gas wasted. In larger plants a check on the gas consumed in the boiler and the gas wasted might lead to a later justification of power development. The metering of the gas consumed by each gas engine is very important, as it will give a good check on the operating efficiency.

Having determined the quantity of gas being handled, it is desirable to check the operating pressures at critical points throughout the system. With suitable U-gauge manometers or pressure gauges placed at such points, it is possible for the operator to check at a glance pressure losses throughout the system. An abnormal pressure drop at any point in the system can be noted, and this will usually indicate to the operator that some portion of his system is not functioning correctly. Possibly a water block has developed as a result of neglecting to drain the condensate from some point in the system. This immediately shows up and can be located and remedied. Trouble may develop in one or more of the gas meters, either through moisture or through some other cause developing an excessive loss through the unit; or a flame trap element may need cleaning. With proper pressure indication, the source of trouble may be easily isolated and corrected.

While no portion of a sewage treatment plant presents a greater hazard than the gas utilization system, with thoughtful design and installation and conscientious operation, most of the hazard can be eliminated. Only by working together and profiting by operating experience can the most efficient and simple solution be found. To that end it is hoped that this paper will bring forth discussions and solutions of some of the problems which have been experienced.

References

1. New Jersey Sewage Works Assn., Joint Committee Report. "Gas Hazards and Their Elimination." *Mun. San.*, 10, 394–396 (1939).
2. *Ibid.*, 453–454 (1939).

3. *Loc. cit.*, 489–490 (1939).
4. *Loc. cit.*, **11**, 23 (1940).
5. Wellington Donaldson, "Gas Collection from Imhoff Tanks." THIS JOURNAL, **1**, 608–614 (1929).
6. Weston Gavett, "Gas Collection from Digestion of Activated Sludge at Rockville Center, N. Y." THIS JOURNAL, **3**, 615–620 (1931).
7. "Percolation Beds Provide Disposal of Sewage Plant Effluent." *Eng. News-Rec.*, **3**, – (April 23, 1931).
8. Willem Rudolfs, New Jersey Agr. Exp. Station *Bull.* No. 427 (1925).
9. John R. Downes, "Gas Collection and Sludge Heating." THIS JOURNAL, **4**, 72–82 (1932).
10. A. J. Fischer and F. Quimby, "Sludge Heating and Gas Collection at Antigo, Wisconsin." *Pub. Works*, **59**, 382–387 (1928).
11. Henry Liebman and E. J. Fort, "Tallmans Island Sewage Treatment Works." THIS JOURNAL, **11**, 251–263 (1939).
12. "Gas Production, Purification and Characteristics." *Mun. San.*, **9**, 582–584 (1938).
13. A. S. C. E. Committee on Sludge Digestion. "Characteristics of Sewage Gas and Gas Utilization at Plants." *Mun. San.*, **8**, 450 (1937).
14. R. R. Sayers, "Gas Hazards in Sewers and Plants." *Mun. San.*, **5**, 262–266 (1934).
15. G. W. Jones, "Explosion and Health Hazards in Sewage Works Operation." THIS JOURNAL, **5**, 289–301 (1933).
16. LeRoy W. Van Kleeck, "Safety in Maintaining Sewers and Sewage Treatment Plants." *Pub. Works*, **69**, 20–22 (No. 8) (1938).
17. Paul J. Houser, "Hazards and Safety Measures at Sewage Works." THIS JOURNAL, **10**, 731–737 (July, 1938).
18. S. H. Ash, "Detection and Measurement of Certain Types of Gases." THIS JOURNAL, **5**, 662–673 (1933).
19. W. H. Wisely, "Sewage Plant Operation, Part VIII, Gas Collection and Utilization." *Mun. San.*, **9**, 82–85 (1938).
20. W. H. Wisely, "Sewage Plant Operation, Part IV, Sludge Treatment and Disposal." *Mun. San.*, **8**, 455–458 (1937).
21. LeRoy W. Van Kleeck, "Safety Measures for the Operation of Sewage Treatment Plants, Part III, Gas and Fume Dangers." *Mun. San.*, **8**, 366–368 (1937).
22. *Ibid.*, Part IV, *Mun. San.*, **8**, 411–414 (1937).
23. *Ibid.*, Part V, *Mun. San.*, **8**, 459–461 (1937).
24. John R. Downes, "Safety in Sludge Gas Collection." *Eng. News-Rec.*, **3**, 897–898 (1931).
25. C. E. Keefer, "Preventing Gas Explosions in Sludge Digestion Tanks." *Eng. News-Rec.*, **122**, 66 (No. 10) (1939).
26. "Eliminating Gas Explosion Hazards in a Sewage Disposal Plant." **123**, 66 (No. 19) (1939).
27. John R. Downes, "Sludge Digestion Tank Explosions." *Mun. San.*, **2**, 548 (1931).
28. Robert M. Cadman, "Fire and Explosion Hazards at Sewage Works." *Water Wks. and Sew.*, **85**, 259 (1938).
29. "Sludge Gas Explosion at Sewage Works, Woonsocket, R. I." *Water Wks. and Sew.*, **78**, 284 (Oct. 1931).
30. "Gas Explosion Damages Bristol, R. I., Sewage Works." *Water Wks. and Sew.*, **83**, 91–92 (1936).
31. "Sewage Gas Explosion Damages Dayton Sewage Treatment Plant." *Mun. San.*, **9**, 572 (Dec. 1938).
32. "Gas Explosion at Dayton Sewage Treatment Plant Believed Due to Spark from Motor." *Mun. San.*, **10**, 25 (1939).
33. Editorial, "Lethal Gas." *Water Wks. and Sew.*, **79**, 223 (1932).
34. Lawrence Luther, "Hazards at Sewage Treatment Plants." *Water Wks. and Sew.*, **86**, 32–34 (1939).
35. L. L. Langford, "Gas and Oil Heating Equipment." *Water Wks. and Sew.*, **84**, 416–417 (Nov., 1937).
36. Combs, M. A., "Automatic Gas Heating Equipment Design." *Mun. San.*, **9**, 568–571 (1938).

Editorial

WILLIAM WALLACE BUFFUM

Although Mr. Buffum had been ill for several months, the news of his death on June 22nd was quite a shock to his friends and associates. He died from a heart attack at his home in Montclair, New Jersey.

Mr. Buffum was born in Friendsville, Pennsylvania, 52 years ago. He became associated with Mr. Francis Garvan, the Alien Property Custodian, during the war, from 1917 to 1921, and following the War Mr. Buffum was made Treasurer and General Manager of the Chemical Foundation, which office he held until his death. The work he did here for advancement of chemical research in the United States will stand as an eternal tribute to the unselfish devotion and loyalty he showed in all his relations with his fellow men. He helped many scientific journals to get started, and at the time of his death was business manager of the *American Journal of Cancer*, the *Journal of Clinical Investigation* and the SEWAGE WORKS JOURNAL. His aid to our journal has been unfailing since it was started in 1928.

Resolutions have been adopted by the Board of Control of the Sewage Works Federation, as printed below, and a personal memoir has been kindly prepared by Dr. Rudolfs. These expressions of esteem and sympathy show the affection in which Mr. Buffum was held by his friends and associates. He will be sadly missed by them.

Just as we go to press we learn of the unexpected death on July 20th of Mr. Jay R. Gilbert, President of the Lancaster Press, publishers of the SEWAGE WORKS JOURNAL. Mr. Gilbert had long been a friend of Mr. Buffum, and in a letter to the writer dated June 26, Mr. Gilbert said "We have all lost a very good friend and it is certainly too bad that a man of only fifty-two years should be taken away. I attended the funeral on Monday and had a short visit with Mrs. Buffum and the children afterwards."

It is a doubly hard blow to announce the deaths of these two friends and co-workers on the SEWAGE WORKS JOURNAL.

F. W. MOHLMAN

Personal Memoir by Dr. Rudolfs

William Wallace Buffum, Treasurer and Director of the Chemical Foundation and Business Manager of the SEWAGE WORKS JOURNAL since its inception, died on June 22nd after a brief illness caused by a heart ailment. He was fifty-two years old.

Since 1921 Mr. Buffum has been a member of the Chemical Foundation and took an active interest in the furtherance of chemical education in this country and in the organization of scientific societies. His greatest interest was in the utilization of chemistry in the fight against various diseases and the development of newsprint from Southern pine. Through his connection with the Chemical Foundation and his interest in fighting diseases he became business manager of several periodicals, including the SEWAGE WORKS JOURNAL.

Sometime in 1924 "Buff," as he was affectionately known to many, found that the Chemical Foundation as agents had considerable income from patents on Imhoff tanks taken over during the World War by the Government and handled in the office of the Alien Property Custodian. After several conferences the sum of $2,000 was made available for sewage research. Mr. Buffum was continuously on the lookout to further research and during the following years the sums of money for sewage research were gradually increased. To stimulate sewage research throughout the country, a number of conferences were held which were expanded to larger groups of men interested in sewage treatment problems, methods of control and analyses and the formation of an organization national in scope. Of especial importance to the profession in general and the dissemenation of information in particular was the conference held in the spring of 1928

at St. Louis during the meetings of the American Chemical Society. A movement was on foot to find proper means for publishing research and operating papers and for the formation of a Federation of Sewage Works Associations. Mr. Buffum was much interested and suggested that the Chemical Foundation could be of material help. On April 25, 1928, a meeting was called in Mr. Buffum's office in New York with Mr. Wm. Orchard, C. A. Emerson and the writer of this note present, to discuss the publication of a Sewage Works Journal. Mr. Buffum agreed to take on the business management of the Journal, to attend to solicitation of subscriptions, take care of all advertising, keep records and accounts, print and mail the magazine quarterly, and meet any deficit incurred. This arrangement was to be for one year, but ever since the publication of the JOURNAL Mr. Buffum remained as Business Manager.

Those who have come in contact with Mr. Buffum can appreciate his work and encouragement to stimulate development and research in sewage treatment. His identification with the JOURNAL made it financially possible to reach a large number of sewage plant operators. His interest was an important factor in the rapid growth of sewage research, which has made this country the leader in the world. He was always ready to support any movement to fight diseases and secure cleaner streams. In the earlier years of the Federation his advice and help was an important factor in the rapid growth of Sewage Works Associations in this country. His business-like manner in handling the affairs of the JOURNAL, his sympathy and support carried the JOURNAL over several difficult periods.

As a man, Mr. Buffum was liked for his integrity and kindness. His straightforwardness made it a pleasure to be associated with him. Fairness and fair play, impartiality and faithfulness guided his actions with those he trusted. He was not a man to make long speeches or have long deliberations; his actions were quick and decisive. His greatest joy was a job well done and success in ventures begun. He never interfered or tried to influence Federation affairs; always hiding behind "I know nothing of the technical side of sewage problems," but ready to carry out any reasonable request and to support sound suggestions. He did not look for personal gain or aggrandizement. He served for the common good. He was one of the few, difficult to replace.

WILLEM RUDOLFS

Resolutions on the Death of William W. Buffum

By the Federation of Sewage Works Associations

WHEREAS, in the death of William W. Buffum the Federation of Sewage Works Associations has suffered the loss not only of its Business Manager but also of one who was largely instrumental in its creation and success, and

WHEREAS, the Federation was made possible and its continuance assured because of the financial assistance brought to it through him during early years of its existence; and

WHEREAS, in times of doubt as to the possibility of continuing the organization, his enthusiasm and unfailing faith in its future were an inspiration to his official associates; and

WHEREAS, he gave generously of his time and energy throughout all the years of its existence in furtherance of its objectives;

Therefore, Be It Resolved, that the Federation of Sewage Works Associations hereby expresses its high appreciation of the services rendered the Federation by William W. Buffum, its admiration for him as a man of sterling character and its regret at his death, and directs that a copy of these Resolutions be officially recorded in the proceedings of the Federation, published in SEWAGE WORKS JOURNAL and that copies be sent to the family of the deceased and to The Chemical Foundation.

Proceedings of Local Associations

MICHIGAN SEWAGE WORKS ASSOCIATION

Fifteenth Annual Meeting, East Lansing, Michigan, May 8–10, 1940

The fifteenth annual meeting of the Michigan Sewage Works Association was held at Michigan State College, East Lansing, Michigan, on May 8–10, 1940. The Conference was preceded by a short course school of instruction given by Dr. W. L. Mallmann, E. F. Eldridge and F. R. Theroux of the College faculty. Sixty-four students registered for the short course work and a total of 164 were present at either the school or Conference. The popularity of this short course is increasing so rapidly that plans are being considered to provide additional facilities in coming years.

The Association was most fortunate in the quality of material presented this year and the many excellent papers aroused active discussion among those present following the presentation.

Mr. George F. Wyllie gave an excellent description of his experience at the Lansing sewage treatment works in handling mixtures of sludge and garbage on a full plant scale of operation. His paper presented both the achievements and the difficulties encountered and represents a distinct addition to an extremely limited fund of authentic information on this important subject.

Due to the inability of Mr. Heeg to appear on the program as scheduled, the meeting was opened for discussion of the problem of handling supernatant liquor. The discussion ensuing was exceedingly active and indicative of the interest in this problem.

Dr. W. L. Mallmann gave another of his most interesting discussions on efficiencies of sewage treatment plants as measured by bacteriological performance. The title of his paper was "A New Yardstick for Measuring the Removal of Pathogenic Bacteria by Sewage Treatment." In the course of his discussion Dr. Mallmann presented certain data which he had accumulated showing the effectiveness of various types of plants in removing colon organisms and compared this with their effectiveness in removing streptococci organisms. He indicated the possibility of this latter organism being a preferable indicator to the time honored coliform group.

The high capacity trickling filter plant at Mason, Michigan, which has been in service for several months was described by Mr. W. E. Zimmer, the designing engineer, and operating results were given.

The Association was particularly favored by the presence of Mr. Leroy C. Smith of the Wayne County Road Commission who described the very interesting sewage treatment project for the County which he has been directing for the Wayne County Board of Supervisors. This

is a $2,000,000 project designed to handle the sewage from the greater part of Wayne County not served by the Dearborn and Detroit projects.

The membership was happy to again welcome Mr. James R. Rumsey, a past president of the organization, who has been absent from the State for several years while employed on the Buffalo project. Mr. Rumsey spoke on the subject of the design of sewage treatment works from the operator's viewpoint and presented slides of the Buffalo plant to illustrate his points. He was assisted in his presentation by Mr. T. M. Niles of Greeley and Hansen, Chicago.

Mr. L. F. Oeming, Sanitary Engineer for the Michigan Stream Control Commission, presented an interesting discussion on the use of a formula developed by Mr. Streeter of the U. S. Public Health Service in allocating responsibility for bacterial pollution at a point in a stream below several sources of pollution. Mr. Oeming applied this formula to a Michigan stream and demonstrated its applicability and value in a very interesting manner.

A moving picture illustrating lubrication problems was presented by Mr. V. A. Smith, Technical Manager of Socony-Vacuum Oil Company, through the courtesy of the Company. Following this instructive showing Mr. Smith very kindly answered questions on problems of lubrication.

Mr. F. G. Nelson of the Dorr Company gave an interesting talk on digester operation showing from an accumulation of data collected all over the country certain trends in digester performance. He emphasized the difficulty of securing comparable data from different plants because of different methods of operation, varying local conditions, inaccuracy of measurement of quantities and similar factors.

A description of the plant at Ypsilanti, Michigan, and a discussion of the results obtained by flocculation of sewage without the use of chemicals was presented by Mr. T. Fred Older, city engineer. He also discussed the effect of water softening sludge on the Ypsilanti plant.

Due to unavoidable circumstances the Association was deprived of the privilege of hearing Morris M. Cohn, editor of *Municipal Sanitation*. However, Mr. Cohn very kindly forwarded his excellent paper on "Sewage Treatment, A Problem in Public Service and Public Relations" which was presented by Mr. N. G. Damoose, Engineer-Manager of the Battle Creek sewage treatment plant.

At the business meeting the following officers were elected:

President: A. B. Cameron, Jackson
Vice-President: J. C. Marshall, Charlevoix
Director: J. F. Leemaster, Jackson
Continuing Dir.: Robert Musgrove, Grand Rapids
Sec'y-Treas.: W. F. Shephard, Lansing

President Cameron reappointed E. F. Eldridge and N. G. Damoose as representatives to the Federation Board of Control for the next year.

A resolution was adopted requesting the Board for Certification of

Sewage Plant Operators appointed by the State Commissioner of Health to proceed with a plan for examining and issuing certificates to operators on a voluntary plan.

Following considerable discussion two resolutions were adopted relative to the proposed plan of re-organizing the Federation. The first resolution adopted instructed the President of the Michigan Sewage Works Association to continue a committee in existence for further consideration of the matter of re-organization of the Federation, and that this committee together with the officers of the Michigan Sewage Works Association be given power to receive and act upon whatever proposal may come before them during the coming year relative to such proposed change in the Federation.

The second resolution adopted pertaining to this matter was as follows:

Whereas, the Michigan Sewage Works Association recognizes the rapid progress in the science of sewage treatment and,

Whereas, this progress entails wider distribution of ideas and dissemination of pertinent information through more frequent publication of the *Sewage Works Journal,* and

Whereas, such extension of activity and promulgation of the advancement of this science can only be achieved by a legally instituted national body, be it therefore

Resolved, that the Michigan Sewage Works Association heartily approve of the institution of a working committee to study the necessary revisions and extensions of the Federation of Sewage Works Association for this purpose, subject to the following provisions:

(1) That the identity and function of the local associations shall not be impaired,

(2) That the membership fees for full active membership in the Federation by sewage plant superintendents, operators or others engaged in the operation of a sewage plant shall not exceed $3.00 per annum including the subscription to the *Sewage Works Journal.*

Respectfully submitted,

E. F. Eldridge
Tom Doyle
N. G. Damoose
James Rumsey
R. J. Smith
Charles Meserva
W. F. Shephard, *Secretary*

OKLAHOMA WATER AND SEWAGE CONFERENCE

Sixteenth Annual Meeting, Stillwater, Oklahoma, January 22–26, 1940

The Sixteenth Oklahoma Water and Sewage Short Course was held at the Oklahoma A. and M. College at Stillwater, January 22–26, 1940. Eighty-seven men were registered during the course. Cost accounting was the key subject for the short course this year. Dr. William D. Hatfield, superintendent, Decatur Sanitary District, Decatur, Illinois, presented a general outline of sewage treatment processes and afterwards conducted a clinic on sewage treatment problems. We feel that we were very fortunate in having Doctor Hatfield present at the short course.

Mr. W. Scott Johnson, Chief Public Health Engineer of the Missouri State Board of Health, gave a lecture on hazards of faulty plumbing, illustrated with lantern slides and movies, and this talk created an unusual amount of interest and discussion among the men.

PAUL C. HENDERSON

CALIFORNIA SEWAGE WORKS ASSOCIATION

Twelfth Annual Spring Conference, Avalon, California, May 20 and 21, 1940

President Harold G. Smith called the meeting to order promptly at 9:00 A.M. on Monday, May 20. A short introductory speech called the attention of the 93 members and guests present to the charm of the meeting place, Catalina Island, and bid those present welcome.

As there was a full program the business meeting proceeded rapidly. A report of the Award Committee was presented by Albert J. Castro, Jr. The report is published in the *California Sewage Works Journal.*

Richard Pomeroy presented a progress report of the Fact Finding Committee on Design-Standards. He stated in essence that investigation made by the Committee had revealed a woeful lack of information available at the plants and offered the recommendation of the Committee that the State Board of Health be solicited in an effort to improve plant operation through field equipment and personnel. Acting on the recommendation, the members moved, seconded, and carried by unanimous vote that the Governing Board be instructed to adopt a resolution appropriate to the sense of the recommendation.

The report of the Publicity Committee was read by the Secretary. Mr. John A. Clark called attention to publicity in *Water Works and Sewerage, Western Construction News,* and *Western City,* as well as 75 column inches devoted to activities of the Association at Oakland September 18–19, 1939.

William A. Allen reported on the Operators' Breakfast. Eighteen members attended and 12 were directly connected with plant operation. Withdrawal of sludge from primary sedimentation tanks, digester

heating and coil maintenance, and the sale of sludge for fertilizer received their due in a lively discussion. J. C. Clark exhibited an ingenious gadget for removing the balls from ball-check valves in sludge pumps.

Mr. J. F. Smith reported on finances of the *California Sewage Works Journal*. He stated that a program of increased advertising in that journal was being promulgated.

The above reports were accepted and the business meeting was adjourned to a later hour.

The technical program began appropriately with an excellent historical paper, "Sewage in Ancient and Medieval Times," by Harold F. Gray, Consulting Engineer. Mr. Gray's paper was accompanied by slides.

Mr. Reuben F. Brown, Assistant Superintendent, Sewer Maintenance, Los Angeles, followed with a supplementary paper, "Methods and Problems of Sewer Maintenance, City of Los Angeles, California," and also accompanied his paper with slides. Mr. Fred D. Bowlus, Assistant Engineer, L. A. Co. Sanitary District, presented a written discussion of Mr. Brown's paper offering the problems of the Los Angeles County Sanitation District. Mr. A. M. Rawn offered extemporaneous comment on both the paper and the discussion.

Dr. Richard Pomeroy, Research Chemist, offered a thought provoking paper, "Laboratory Tests for The Sewage Plant Operator." A lively discussion participated in by Messrs. A. C. Beyer, Fred Post, H. G. Smith, A. M. Rawn, and J. C. Clark followed the paper.

The business meeting resumed at 11:45 A.M. At this time Mr. W. T. Knowlton discussed the Institute of Government to be given at the University of Southern California in June. Mr. Knowlton called attention to the section on water supply, plumbing, and sanitary engineering. "Under this heading many subjects of interest to men in the sewage works field are to be given," Mr. Knowlton said. He urged those who found it possible, to attend.

Mr. Jack Kimball gave a brief report of Membership Committee activities. He called particular attention to the many junior engineers who do not share in the activities of the Association. The membership for the year was reported as quite satisfactory with 235 members as of May 1, 1940. Of these 29 were new members. Copies of the Constitution and By-Laws of the Association are to be used by Committee in contacting possible members according to Mr. Kimball.

President Smith introduced new members of the Association and asked that those guests present be introduced.

After adjournment for lunch, the business meeting was reconvened at 2:00 P.M.

Albert J. Castro and A. C. Beyer opened a discussion of the future of the Award of Merit. Mr. A. M. Rawn commented on the Award with the suggestion that the Award be made only to plants that were operating at design capacity. The general opinion seemed to be that the Award was well worth continuing.

President Smith called the technical session for the afternoon at 2:10 P.M. with a most interesting and timely paper, "Electrical Equipment in Sewage Pumping Plants and Treatment Plants," by Mr. Frank A. Short, Engineer, Industrial Accident Commission, State of California.

Franklin B. Thomas, Professor of Civil Engineering, California Institute of Technology, then presented a paper, "The Sewage Situation of the City of Los Angeles." Harold F. Gray read a discussion of Professor Thomas's paper which had been prepared by Professor Charles G. Hyde.

Continuing a line of thought offered at the Twelfth Annual Fall Meeting of the Association, Paul A. Shaw, Pollution Detail, California Division of Fish and Game, presented a paper, "Pollution Control Work of the California State Division of Fish and Game."

Mr. Adolf H. Koebig, Jr., Consulting Engineer, asked that his paper, "Covina Sewage Treatment Plant," be presented by Mr. Ted Gregory of his office. Mr. R. F. Goudey enlarged upon the written discussion of Mr. Koebig's paper. Discussion from the floor followed with Messrs. Phelps, Rawn, Pomeroy, and Bowlus participating.

The meeting adjourned at 5:00 P.M. with the announcement of President Smith that the banquet would be held in the Mirror Room of the Hotel St. Catherine.

During the evening President Smith called attention to the very fine work accomplished by the Local Arrangements Committee headed by Howard Jewell. Vigorous applause indicated the appreciation of the members.

Dean W. Ballentine Henley, of the University of Southern California, as guest of the meeting, offered a philosophical and yet practical subject, which he entitled "Beautiful Mud." The subject was far afield from the technical aspect of the Association, and as such, was thoroughly enjoyed by the audience.

The meeting was called to order at 9:15 A.M., Tuesday, May 21, and President Smith asked Mr. B. D. Phelps, Assistant City Engineer, City of San Diego, to present, "The Maintenance of Sanitary Sewers in San Diego, California." Carl M. Hoskinson discussed Mr. Phelp's paper.

During the Operators' Symposium, the following subjects were discussed: "Gadgets," by A. E. Fiscus, Terminal Island; "Sludge Beds," Carl Tennant, Los Angeles, Co. Sanitation District; "Experience in Remodeling Mechanical Aerators in Laguna Beach Plant," R. D. Woodward, Laguna Beach; "Sludge Pump Control," Verner C. Johnson, Covina; "Cause, Effect, and Removal of Scum Formation in the Digester at the Palo Alto Treatment Plant," Harold L. May, Palo Alto. Mr. May's discussion was read by Mr. Jack Kimball.

A general discussion followed with Messrs. Pomeroy, Kelly, Rawn, Wirt, Ingram, Knowlton, Towers, and Gray participating.

After a short recess, the illness of Past President Alexander Bell, was reported and a telegram to Mr. Bell was authorized by acclamation.

Mr. E. G. Studley, Assistant Civil Engineer, City of Los Angeles, presented a paper, "Experiments Conducted at the Los Angeles City Pilot Plant," which had been prepared jointly by Mr. Studely and H. G. Smith, Engineer of Sewer Design, City of Los Angeles. Verbal discussion by J. C. Clark, A. M. Rawn, and Richard Pomeroy followed the paper and Earl M. Kelly offered a written discussion.

President Smith called upon William O. Kyte, of the General Electric Co., to present Mr. L. M. Best of the same company. Mr. Best commented at some length on his written paper, "The Care of Motor Bearings," and answered several questions from the floor in this connection.

The meeting was closed at 1:15 P.M. by President Smith who expressed his thanks to the group and reminded them that an excellent meeting was in prospect at San Diego, California, in September.

WILLIAM T. INGRAM, *Secretary*

NEW YORK STATE SEWAGE WORKS ASSOCIATION

Spring Meeting, Syracuse, New York, June 20–22, 1940

The New York State Sewage Works Association held its Spring Meeting at the Hotel Syracuse, Syracuse, N. Y., June 20, 21, 22, 1940, President C. G. Andersen presiding. One hundred and seventy members and guests including twenty-five ladies were registered. The exhibits of twenty-three manufacturers were instructively displayed in very attractive booths in the ballroom of the hotel.

Following registration Thursday noon the convention opened with a brief business meeting followed by the technical session, at which Clarence MacCallum, Mineola, N. Y., presented a paper on "Training Operators of Sewage Treatment Plants," which, with the discussion that followed, was very helpful. William Gyatt, Syracuse, N. Y., gave a paper on the "Operation of the Main Sewage Treatment Plant at Syracuse." Dr. George L. Wright, Surgeon of the Syracuse Fire Department, with a special squad of city firemen gave a demonstration with running comments on "First Aid," which was of special interest to all. A joint paper by Messrs. C. R. Velzy, J. W. Johnson and George Symons of the Buffalo Sewer Authority on "Operating Experiences in Sewage Treatment at Buffalo" gave a splendid picture of the largest upstate sewage treatment works.

The association gave a hearty welcome to its past president, John F. Skinner of Glendale, Calif., who spoke briefly on engineering experiences in the far west.

Thursday evening was manufacturers' night, with inspection of exhibits, and a general social time and light refreshments in the ballroom.

The technical session on Friday morning opened with a "Symposium on Sludge Filtration and Incineration" under the leadership of

William Raisch, New York City. Mr. Raisch opened the discussion with a very comprehensive, yet concise paper on the subject and was followed by four papers presented by superintendents of sewage treatment plants, giving their operating experiences, C. R. Velzey (Buffalo), J. T. Lynch and H. E. Milliken (Auburn), G. J. McInerney (Elmira), W. D. Denise (Greece).

Glenn D. Holmes, Director and Chief Engineer of the Onondaga Public Works Commission, gave an illustrated "Description of the Ley Creek Sewage Treatment Plant."

At the luncheon Friday, Dr. P. J. Rafle, District State Health Officer, welcomed the group on behalf of the State Health Department and Hon. James R. Vedder, Chairman of the Onondaga Public Works Commission, spoke of the work of the commission in Onondaga County. The Rating Committee award in the form of an engraved silver loving cup was presented to Reginald A. Murphy of Willard State Hospital by C. C. Agar, Chairman of the Rating Committee. This award is presented annually to the operator who submits the operating report receiving the highest rating.

Friday afternoon was devoted to an inspection of the Ley Creek sewage treatment plant. This is an activated sludge plant serving the eastern and northern portion of the city of Syracuse, the village of East Syracuse and other areas immediately north of Syracuse.

Also on Friday afternoon the ladies had luncheon at the Drumlins Country Club and made a tour of inspection through the plant of the L. & J. G. Stickley Furniture Company at Fayetteville. Friday evening the usual banquet and entertainment were enjoyed.

Saturday morning after the "Sunrise" breakfast, Morris M. Cohn conducted the "Peddlers Patter" session and also the question box period where troubles are diagnosed and prescriptions given.

The next meeting of the association will be the Annual Meeting in New York City in mid-January 1941.

A. S. Bedell, *Secretary*

Reviews and Abstracts

WAKEFIELD SEWAGE WORKS: NOTES ON OPERATION

By L. J. Artist

The Surveyor, **97**, 215–7 (March 1, 1940)

The remodeled main sewage disposal works at Wakefield were officially opened on May 6, 1936. The plant receives a daily dry weather flow of 2.70 m.g.d., with an average daily flow of 4.07 m.g.d. This flow is augmented by the return of filter effluent for raw sewage dilution and "make-up" water. During storm periods up to 4.6 times the dry weather flow is given activated sludge treatment, excess flows being by-passed direct to the river.

The dry weather sewage is approximately 50 per cent of domestic origin and the remainder trade wastes from wool textile plants, breweries, laundries, iron wire cleaning and plating, and dairy products.

The sewage receives preliminary treatment by mechanically cleaned bar screens, detritus tanks, and manually cleaned settling basins. There are four of the latter units, two of which are normally used, affording a detention of about 6 hours. Daily variations in sewage flow are "ironed out" to a considerable extent by using a spare settling tank as a flow equalizing unit.

In summer, the sewage is chlorinated before sedimentation to minimize septic action. Only about 5 p.p.m. chlorine is used although the demand averages about 40 with a range from 10 to 350. When exceptionally strong sewage is being received, 300 to 400 p.p.m. aluminoferric is dosed to the settling tank influent.

There are four bio-aeration tanks of the paddle type, providing a normal detention of about 13½ hours. Sludge concentration is maintained at approximately 800 p.p.m. Return sludge concentration amounts to about 2,500 p.p.m.

Activated sludge effluent up to 2.3 times the dry weather flow is passed through trickling filters and humus tanks. The filters have an area of 3¼ acres and are equipped with rotary distributors.

Sludges from the various treatment stages are disposed of to farmers or are trenched on the works grounds. Farmers readily take the air dried detritus tank sludge and air dried product from the open earth embarkment digestion tanks. The latter units handle all the waste activated sludge but the bulk of the entire plant sludges is disposed of on the trenching areas.

Treatment results from the three years 1936–7 to 1938–9 are shown in the following table:

Wakefield Sewage: Analyses: P.P.M.

	Detritus Effluent	Tank Effluent	Aeration Unit Effluent	Humus Tank Effluent
Suspended solids	365	183	36	17
B.O.D.	180	100	28	13
NO_3 Nitrogen	—	—	—	11.4

Detailed costs of treatment are given in the article. Total cost amounted to £11 17s. 3d. per m.g. average daily sewage flow, of which £5 2s. 1d. was for capital charges and 6s. 9d. for pumping.

V. G. MacKenzie

OLDHAM'S RECONSTRUCTED SEWAGE PURIFICATION WORKS: NOTES ON OPERATION

By J. Taylor

The Surveyor, **97**, 169–71 (Feb. 16, 1940)

The reconstructed sewage purification works of the Oldham Corporation, officially opened in 1938, serves a present population of approximately 130,000 contributing an average dry weather flow of 4.25 m.g.d. The district is very hilly and is sewered on the combined system. The sewage is mainly domestic with about 0.2 per cent gasworks liquor. In time of storm, complete treatment is given to three times the dry weather flow and sedimentation to flows up to six times the dry weather average.

Before plant alterations, treatment was furnished by the following units: detritus chambers, sedimentation tanks, contact beds, percolating filters, humus tanks, storm tanks, sludge lagoons.

Where possible, existing structures were used in the alterations for economy. Coarse screens have been added and the detritus tanks reduced in capacity to improve the quality of the grit collected. The existing forty year old manually cleaned sedimentation tanks were retained, their structural condition being sound. There are nine of these units, each of capacity of one hour's dry weather flow. Storm water treatment is furnished by five additional plain settling basins, the sludge being returned to the plant influent.

Following sedimentation the sewage receives activated sludge treatment followed by percolating filters and secondary sedimentation.

The aeration plant consists of seven units, with total capacity 993,000 gallons, which may be used for aeration and sludge reaeration. Best average results have been obtained by using three tanks for aeration and four for sludge reaeration. Aeration is by diffused air; air consumption has averaged 0.40 cu. ft. per gallon of sewage treated.

The activated sludge settling tanks are equipped with rotating mechanism from which ¼ inch steel chains are suspended loosely and scrape the tank floors.

The pretreated sewage is dosed on the trickling filters at about 90 gallons per cu. yd. The filters are equipped with rotary distributors and arranged so that double filtration may be used if found necessary. Filter effluents, before discharge, are settled for approximately 2.6 hours in plain humus tanks equipped with fine stone filters at the outlet end.

All sludge produced is discharged back to the primary settling tanks whence approximately 130,000 cu. ft. per month of 92.5 per cent moisture combined sludge is dosed to the digesters. Two stage digestion is used, the primary tanks being heated and with gas collection facilities and the secondary units being open and unheated. Approximately 235,000 cu. ft. capacity is furnished in each stage. In 1939 digester operation resulted in a reduction in sludge volatile matter of 45.7 per cent.

Digested sludge is dried on sand beds having a total area of 29,750 sq. yds. Depths of 12 to 18 inches have taken three to seven months to dry depending upon the weather.

Average analytical results for 1939 are partially given below, expressed in p.p.m.:

	Raw Sewage	Settled	Activ. Sludge Effluent	Final Effluent
4 Hr. Ox. absorption (26.7° C.)	58.1	49.1	21.5	10.2
5 Day B.O.D. (18.3° C.)	—	—	32.0	11.1
NO_3 Nitrogen	—	—	1.80	23.3
Suspended Solids	172	91	38	22

Vernon G. MacKenzie

BRADFORD SEWAGE WORKS PRODUCTS

The Surveyor, **97**, 271 (March 22, 1940)

At Bradford, one-fifth of the world's wool and four-fifths of that grown and imported into England is washed and processed. For treatment of the resulting wastes and recovery of grease and other products therefrom, a plant has been built over the years at a cost of 2.75 million pounds.

The recovery of grease at these works has grown from 166 tons in 1903 to over 7,000 tons per year in late 1920's. The successful marketing of the large quantities of recovered grease has been a problem at times. However, research has led to a widening of the market through the production of clarified greases and other products more suitable for industrial uses than is the ordinary quality of recovered grease, and over £33,000 has been received through the sale of such items.

Prices received for the recovered grease have fluctuated widely, ranging from a high of over £63 per ton in 1918 during war time to £8 to £9 per ton during normal peace times. The outbreak of the recent war has stimulated the demand for this product and it is anticipated that grease sales for the year ending March 31 will exceed £80,000.

Considerable income is also realized from fertilizer sales. The dried sludge is produced at a moisture content of about 15 per cent, some 80,000 tons being available each year. The peak year in sales for this material was in 1921, when £13,655 was realized.

V. G. MacKenzie

ADMINISTRATION OF THE PUBLIC HEALTH (DRAINAGE OF PREMISES) ACT, 1937, WITH SPECIAL REFERENCE TO SMALL AUTHORITIES

By Reginald Dart

The Surveyor, **97**, 145–7 (Feb. 9, 1940)

The Public Health Act of 1936 and the Public Health (Drainage of Trade Premises) Act of 1937, have completely altered established prineiples governing the admission of trade wastes to public sewers and has set up a reasonable degree of uniformity in this matter throughout England.

Previous legal provisions, based on the Rivers Pollution Prevention Act of 1876, directed local authorities to give facilities to manufacturers for disposal of trade wastes, but exempted the authority from any obligation to do so where such liquids would prejudiciously affect the sewers or treatment process or where the sewers were only sufficient for the other requirements of the district. Under these provisos, the obligations of local authorities regarding trade waste drainage were easily avoided.

Under the new acts, local authorities are directed to admit to the public sewers the wastes from manufacturers in the district, upon application for this service. Local authorities are empowered to make ordinances and rulings with respect to trade waste discharges and concerning: (1) The period of the day during which trade effluents may be discharged, (2) The exclusion of condensing water, (3) The elimination of any constituent which would injure or obstruct the sewers, or make the sewage especially difficult or expensive to treat, or cause injury or obstruction to navigation in harbor or tidal waters (where the sewers discharge to such location), (4) The maximum rate and daily quantity of trade waste discharge, (5) Temperature and pH of discharged waste, (6) Payment for admission of the trade waste to the sewers, regard being had to volume and composition, (7) Provision and maintenance of meters for measuring the waste and for inspection chambers for taking samples. For the guidance of local governments the Ministry of Health has issued model by-laws covering the above matters.

Local authorities may make such conditions regarding trade waste discharges as are consistent with the provisions above. Any manufacturer aggrieved by refusal to give

consent to trade waste discharge, or by conditions attached thereto, may appeal for redress to the Minister of Health who is empowered to override such local rulings as are inconsistent with the purposes of the act.

One section of the new legislation, which is causing dissatisfaction among local authorities, establishes a prescriptive free right of traders to discharge of wastes in quantity and composition equal to that discharged into the sewer system at any time during the year ending March 3, 1937. The determination of discharges which are thus exempted from charges is a matter of considerable difficulty.

The author gives an account of the initiation of administration of provisions of the legislation in the urban district of Turton, with a description of the by-laws and schedule of charges relating to admission of trade effluents into the district sewers.

(*Note by abstractor.*—Many articles on the above new legislation have been appearing currently in English journals. The general opinion seems to be that the working of the act will be helpful in the elimination of pollution in that more industrial wastes will be handled at municipal plants where proper physical equipment and operating technique will be available for their treatment. There are some complaints about the legislation, local authorities particularly being dissatisfied with the traders' prescriptive right of discharge, and some manufacturers resenting the conditions attached to the discharge of their waste. There has been much discussion of the charges to be made for waste handling and the limitation of strength of waste constituents. In this connection, some local authorities have favored the making of agreements regarding waste discharge with their manufacturers, rather than the formulation of rigid by-laws.)

V. G. MacKenzie

SOME COMMENTS ON RECENT EXPERIMENTS ON ACTIVATED SLUDGE

By H. H. Goldthorpe

The Surveyor, **96**, 402 (Nov. 10, 1939)

In a previous paper by the author, it was shown that the rate of supply of oxygen in most activated sludge plants was intermediate between the high initial demands and the lower later demands of the final stages. This observation has led to the adoption of "tapered" aeration systems in practice.

Very little experimental work has been done in recent years in attempting to increase the rate of transfer of oxygen from the air into the body of the liquid. The efficiency of such transfer is roughly indicated by the power consumption of various aeration systems. The author implies that further experiments on this phase are desirable.

Studies involving the respiratory quotient, *i.e.*, the volumetric ratio of carbon dioxide produced to oxygen used, of activated sludges by various investigators indicate a value lying between 0.5 and 1.0. From these experiments it would appear that much of the purification by activated sludge is due to reactions other than oxidation.

Investigators have shown that a definite quantity of activated sludge will treat only a definite amount of sewage and that sludges near the maximum load limit have a greater demand for oxygen. These observations have led to attempts to find more active sludges, and a search for specific organisms causing oxidation and coagulation. In the course of investigations, it has been shown that certain sludges readily oxidize nitrogenous materials while others are more adapted to carbonaceous matter.

The author concludes that a good activated sludge is one with rapid coagulating effect, which settles rapidly, and which is capable of oxidizing carbonaceous and nitrogenous matter from the start.

OBSERVATIONS ON TEXTILE WASTE TREATMENT

By C. W. Mengel

Civil Engineering, 10, 267 (1940)

Two years ago the City of Greensboro, N. C., constructed a sewage treatment plant to handle combined domestic and textile wastes. The plant consists of a raw sewage meter, comminutors, detritors, flash mixer, flocculator, primary sedimentation tanks, aeration tanks for activated sludge, secondary tanks, digesters, gas holder, elutriation tanks, and vacuum filters. The plant is so arranged that practically any unit may be by-passed, while the several sections of the flocculator, primary, aeration, and secondary tanks may be operated in parallel or in series, providing great flexibility. The plant has a capacity of 6.5 m.g.d. Designed detention periods at this flow for primary, aeration, and secondary tanks are 2.5 hours, 6 hours, and 3 hours, respectively, and the capacity of the digesters is approximately 2 cu. ft. per capita.

For the first six months of operation only domestic sewage was treated. The regular activated sludge plant procedure was followed, with vacuum filtration of sludge after digestion and elutriation. The average removal of suspended solids and B.O.D. were 92.0 per cent and 92.3 per cent, respectively. An average of 0.74 cu. ft. of air per gallon of sewage was used. No particular difficulty in this operation was apparent while domestic sewage was being treated.

Four textile mills are connected to the interceptor. From these plants are discharged almost every type of dye and treatment liquor known in the textile trade, including sulfur black, indigo, kier liquor, raw stock dyes, and hydrosulfite waste. The owner of these mills contributed a portion of the cost of the treatment plant and pays for the chemicals whose use is directly attributable to dye waste treatment.

The wastes first enter collecting ponds and pass through a control device in which the volume may be varied according to the amount of domestic sewage in the sewer. Normal operation in treating the combined wastes provides for the addition of sulfuric acid to adjust the pH and alum as a coagulant, followed by mixing, flocculation, settling, aeration, and secondary settling. When colors are not heavy, flocculation is omitted. When wastes are not being handled the effluent is clear, sparkling, and stable. When heavy quantities of waste, especially kier liquor, are being treated the effluent is clear but has an amber tinge which is not particularly objectionable. The effect of the wastes on the sludge was immediate and pronounced. Activated sludge could not be returned directly to the aerator so provisions had to be made for reaeration in one of the tanks. This prevented bulking and gave a good effluent, provided the air was increased to 1.5 cu. ft. per gal. of sewage. Excess activated sludge could not be returned to the primary settling tank and was sent to one of the elutriation tanks for thickening prior to being pumped to the digesters. The character of the digested sludge changed to such an extent that in order to be able to handle the filter cake the amount of ferric chloride for conditioning after elutriation jumped from 8 to 20 per cent. The cost of operating the plant, exclusive of chemicals added to the raw sewage, averaged $11.59 per m.g.d. for treating domestic sewage only, and $18.54 per m.g.d. for treating the combined wastes. The cost of sulfuric acid and alum averaged $46.32 per m.g.d. The latter cost was borne by the mill owners.

As a result of two years' operating experiences the author concludes that for a mixture of textile wastes and domestic sewage in the ratio of one to ten, or thereabouts, as practiced in this plant that (1) Accepted bases of design for flocculation and secondary sedimentation seem to hold good for mixed wastes as well as for domestic sewage. Detention times in the primary tank should be increased to four hours. (2) Six hours detention in the aerator is sufficient but provision should be made to supply 2 cu. ft. of air per gallon of mixed waste. (3) Digester capacity should be increased. (4) Thickeners should be installed for the waste activated sludge before it goes to the digesters. (5) Study should be given to reactivation of sludge before return to the aerator. (6) Positive pH control for the raw sewage must be provided, with means for automatic chemical

dosage. (7) Corrosion was experienced and calls for design of simple equipment easily replaced or made resistant. (8) High type operators should be employed. (9) Cooperation of industry is vital and (10) Extensive research is needed, together with accurate operating records of existing plants.

ROLF ELIASSEN

A STUDY OF TIDES AND CURRENTS IN THE WATERWAYS OF THE INTERSTATE SANITATION DISTRICT

BY SETH G. HESS

W.P.A. Project, Report 665–97–3–99

Interstate Sanitation Commission, 60 Hudson St., N. Y.

The principal objective of the Interstate Sanitation Commission is the abatement of pollution in New York Harbor and the adjacent waters. The problem is complicated by the great concentrations of population, the many uses made of the waters of the District, and by the complex tides and currents that may carry pollution from one area to another. The information necessary for a complete understanding of the various tidal and current effects in New York Harbor has been gathered over a period of many years by the U. S. Coast and Geodetic Survey, the U. S. Army Engineers, and several municipal agencies. Through the cooperation of the Works Progress Administration these data were compiled and interpreted for this report. The area under consideration comprises five large bays: Upper, Lower, Jamaica, Newark, and Raritan Bays; five straits: The Narrows, Kill van Kull, Arthur Kill, East River, and Harlem River; one large tidal river: the Hudson River; Long Island Sound, and the Atlantic Ocean.

The tides enter this area through the Lower Bay and through the Long Island Sound, the two points being over a hundred miles apart. This, together with the various connections between the rivers and bays, causes complicated time lags in the point of high and low tides. An explanation is given of the causes behind the general tidal phenomena and the types of tides which may occur. Extensive data are presented to show the lunital interval, the duration of rise and the mean range of tides at the various points noted above. Tidal data are included for the Hudson River up to Troy at which point the tide has a mean range of 1.42 feet. Tidal slopes at different hours are also given. The effect of storms or high winds is particularly noticeable in the East River because a northeast wind will pile up water in the Sound and cause a steep hydraulic gradient in this river. The wind may cause similar conditions to prevail in the Hudson River.

Tidal currents are the horizontal movements of the water that accompany the rise and fall of the tide. Tidal and non-tidal currents occur together in the waters of New York Harbor, the actual current at any one point being the resultant of the two classes of currents. The effect of the non-tidal current from the Hudson and other rivers is to increase the strength of the ebb tide flow and the duration of the ebb tide. The tidal movement through the Narrows is of the progressive wave type. In general, the strength of the current at flood averages 1.4 knots and the strength at ebb 1.8 knots, the difference arising from the very considerable amount of fresh water that drains through the Narrows. Tables are given to show the results of observations of tidal currents at many points of interest. Maps also show these currents at different times of the tidal cycle.

The relation of tides to sewage disposal is of primary importance to the Interstate Sanitation Commission. In the vicinity of New York, as in general, the methods of treatment are predicated upon the character of the waterway, the amount of water available for diluting the sewage or effluent, the direction and distance to which harmful ingredients may be transported by the currents, and the use to which the waterway is placed. The waters in the District are divided into two classes: first, those areas which are used for recreational purposes or for the growing of shellfish; and second, those areas which are used primarily for commercial or industrial purposes. The sanitary requirements in the first areas are naturally much higher than is necessary in the second. In fixing the limits of such areas there will always be an intermediate zone in which the tidal currents will transport polluting material from one class of waterway to the other.

New York Harbor as a whole is fortunate in having the Hudson, Passaic, Hackensack, and Raritan Rivers supplying a continuous flow of water which causes the harbor waters to flow eventually into the Atlantic Ocean. The average volume of water passing the Narrows on the incoming tide is 11,000,000,000 cubic feet, and on the outgoing tide is 12,250,000,000 cubic feet. During each tidal cycle of 12.5 hours there is a net seaward movement of 1,250,000,000 cubic feet through the Narrows. Most of this comes from the rivers mentioned above. Detailed figures are also given for each river at different points of sanitary concern. From the large quantity of water circulating in the various channels of the Harbor an exaggerated notion of the flushing action of the waters in the Harbor is frequently entertained. For the greater portion the water that is returned on the incoming tide is not clean sea water but harbor water that has been carried to a lower portion on the preceding outgoing tide. It is the excess of the ebb tide current which eventually carries the sewage out to sea.

ROLF ELIASSEN

PUBLIC WORKS ENGINEERS' YEARBOOK—1940 AMERICAN PUBLIC WORKS ASSOCIATION

Section on Sewerage and Sewage Disposal, pp. 79–128

I. PROGRESS IN SEWERAGE SCIENCE

BY ALBERT P. LEARNED

This article presents a summary of developments during the past decade. Mention is made of installations in large cities and the aid given through the P.W.A. and the W.P.A. The perfection of equipment for the stabilization of sewage has been one of the outstanding developments. The rebirth of chemical precipitation, the expansion of the utilization of sewage gas for power generation, the introduction of magnetite filters, high rate trickling filters, and the flocculation of raw sewage are given consideration. It is pointed out that in recent years no distinctly new processes for sewage treatment have been invented; but rather modifications and improvements have been made in the processes already in use.

II. THE ECONOMICS OF SLUDGE GAS ENGINES

BY MORRIS M. COHN

The Committee on Sewage Disposal of the American Public Works Association is studying the problem of gas engine economies. The use of by-products in industry has led to efficiency in processing which has met with universal public approval. Similarly, the production of sludge gas with valuable B.T.U.'s, and the conversion of these into K.W.H.'s in the gas engine has made it easier for public works officials to obtain the approval of the voters when appropriations are needed. The Committee is now canvassing operation and upkeep costs from cities and manufacturers and will present data later.

III. THE A.B.C.'S OF SEWAGE TREATMENT

BY MORRIS M. COHN

In order that public works officials may persuade the tax-paying public to approve measures providing for stream cleansing, it is necessary for these officials to be conversant with the fundamentals of sewage treatment. This paper endeavors to make clear to the layman by means of familiar illustrations and simple language the definition of sewage, the need for treatment, the removal of solids, the oxidation of organic matter, the removal of bacteria, and the disposal of the effluent and the solids. A plea is made for the intelligent use of public funds through mature study of pollution control, through broad-gauged design, and through sensible supervision and operation by trained and experienced personnel.

ROLF ELIASSEN

SEWER RENTALS

Amer. Public Works Assn. *Bulletin* No. 7, 113 pages (March 6, 1939)

Price, $1.50. 1313 East 60th St., Chicago, Ill.

This bulletin represents a study of the administrative practices employed in connection with the use of service charges to finance the construction or operation of sewerage systems. Sewer rentals are defined as the periodical charges to the users of the sewer system, whether owners or renters, based upon the extent of their use of the system. This is referred to as the financing of sewers on a utility basis. The place a sewer rental system will have must be determined by the effect it will have on various corporations, properties, and individuals, compared with other forms of revenue now in use or available to the municipality.

Data were obtained from over a hundred cities that charge sewer rentals. Consideration was given to cities of sizes from less than 5,000 to more than 100,000. Representative cities from twenty-four states from the Atlantic to the Pacific were chosen to give a fair cross-section of practices used in this country. Tables are presented to indicate the various officials placed in charge of sewer systems, and those responsible for collection of rental charges. Both separate and combined systems were included, as well as those having complete, partial, and no treatment of the sewage. Discussions are presented on billing practices, collection procedures, disposition of revenues, and rate adjustments, as well as other pertinent factors of interest to the public works official.

Sewer rental rate structures are founded upon various bases of charges which may be classified in the following broad categories: (1) a uniform rate; (2) number of sewer connections; (3) type of property; (4) number of plumbing fixtures; (5) water consumption; and (6) metered sewage. Of these, the water consumption and plumbing fixture bases are the most widely used. The majority of cities use a single basis for determining sewer rental charges, except for occasional special industries or other properties where unusual conditions exist. The advantages and disadvantages of each basis are thoroughly discussed. Extensive tables present the breakdown of rates in each city and data on billing, collection, and administrative practices. City officials and consulting engineers will find this bulletin a useful compilation of valuable data on all matters pertaining to sewer rentals.

ROLF ELIASSEN

STUDIES ON RARITAN RIVER POLLUTION, II, 1937–38

BY WILLEM RUDOLFS

New Jersey Agricultural Experiment Station, *Bulletin*, 659, 22 pages, 7 figures, 6 tables (April, 1939)

In 1927–28 an exhaustive study on the pollution of the lower Raritan River and its tributaries was made. Results of this survey were published in New Jersey Agricultural Experiment Station *Bulletin* No. 489 by Rudolfs (*et al*). The objects of this survey were to determine the nature and extent of pollution; to determine the quantity of domestic and industrial waste and its effect upon the river in respect to public health, aquatic life, and recreation; and to provide data and information which could be used for remedial measures. The chemical and biological studies showed that the whole lower river and all its tributaries were polluted to such an extent as to be a potential menace to public health, injurious to aquatic life and unsatisfactory for recreational uses. The pollution also created nuisances which affected real estate. The survey indicated that the pollution load consisted of the raw sewage from 150,000 persons plus an additional 85,000 population equivalent from industries. Of 16 m.g.d of domestic sewage only 3.5 m.g.d. received treatment and virtually none of the 20 m.g.d. of industrial wastes were treated.

Studies were also made by the Port Raritan District Commission, Rutgers University, State Department of Health, and others, and as a result of the cumulative evidence and aroused public sentiment orders for pollution abatement were issued in 1932.

Of 16 proposed sewage treatment plants projected in the river basin four were in operation prior to 1937. Since in another year all new plants would be operating it was considered of theoretical and practical interest to resurvey the river and its tributaries as a part of a project dealing with the effect of waste on the natural purification agencies of streams. The results of this survey are presented in such a way as to make comparisons with the 1927–28 survey possible.

The Raritan River and its tributaries form the largest drainage system in New Jersey. The drainage area is 1,105 square miles. A description of the geological history quality and quantity of water, population and sources of pollution were given in the previously published bulletin No. 489.

A tabulation showing daily mean discharge of the river (above Manville) by months for 1927–28 and 1937–38 is included in the river flow discussion. The data are also presented graphically by mass curves and histograms. The daily mean discharge for the period 1927–28 was greater than that for 1937–38 during 8 months and less during 4 months. The cumulative mean discharge for the year 1937–38 was less than in 1927–28 by 2,550 c.f.s. or 18 per cent. Average discharge, May to September, in 1937, was 601 c.f.s.; in 1927, 946 c.f.s. The cumulative discharge May to September, 1927, was 40 per cent above normal. The 1937 summer discharge is, therefore, considered more nearly normal.

The sampling stations established for the previous survey were again used. Locations and descriptions of the stations are given by means of a table and a map. Because of the mass of data obtained, results were averaged for the period May, 1937, to March, 1938, inclusive. These are shown in tabular form and include temperature, pH, suspended solids, acidity, alkalinity, chlorides, ammonia, nitrites, nitrates, dissolved oxygen (p.p.m. and per cent saturation), B.O.D., total bacteria and coliform organisms. Similar average results for the 1927–28 survey are also included in this table. The data are also presented graphically for both surveys.

The results indicate that both chemical and bacteriological pollution increased from above Raritan to below New Brunswick. Below New Brunswick the amount of dilution water increases greatly because of tidal action and consequently the intensity of the pollution decreases. The results for pH, alkalinity and chlorides were substantially the same during the two survey periods. Due to sewage pollution the chlorides showed a gradual increase in the portion of the stream not subject to tidal intrusion.

From the standpoint of suspended solids which are an indication of water quality the river was in a somewhat poorer condition during the 1937–38 period than during the 1927–28 one.

The increase in the degree of pollution as measured by ammonia nitrogen was found to be materially greater than the lower flow of the river would indicate. The average flow was 18 per cent greater in 1927–28 but the ammonia content was up to four times higher in 1937–38.

In discussing nitrite and nitrate values the author states that when more ammonia is present higher quantities of nitrite and nitrate can be expected if self-purification continues at the same rate. However, when more ammonia is available and the amounts of nitrite and nitrate produced are lower, something must be present to interfere with the biological processes responsible for self purification and stabilization. The average results for nitrite and nitrate indicate that in general these were lower during the 1937–38 survey although the ammonia content was greater.

Comparison of dissolved oxygen data indicate lower values in 1937–38 above New Brunswick, with values below about the same during both surveys. The lower per cent oxygen saturation above New Brunswick is not considered significant in connection with reduced rate of oxidation. It is noted that the B.O.D. of the river at Bound Brook bridge doubled and this increase cannot be accounted for by tributary inflow above this point. Based on these findings with respect to nitrification, dissolved oxygen and B.O.D. the author states that the pollution has definitely increased during the ten year period.

It is further stated that this increase was caused by wastes entering the river between Manville bridge and Bound Brook bridge a section in which there is considerable industrial development.

The author states that the amounts of oxidizable material discharged into the river appear to be somewhat greater during the winter months. This conclusion is based on summer and winter averages of river B.O.D. (at two points) which differed by 0.7 and 0.9 p.p.m. Summer 4.5 and 5.1 p.p.m.; winter 5.2 and 6.0 p.p.m., respectively.

A tabular presentation of the amounts of oxygen present and of the per cent saturation for summer and winter seasons, 1937–38 is given. The results for summer conditions varied from 34 to 80 per cent saturation; winter 61 to 93 per cent. The author states that fish tend to migrate when saturation falls below 50 per cent and that few species remain at values less than 30 per cent.

A graphical presentation of bacteriological data is given. The total number of organisms per cubic centimeter did not vary greatly over the ten year period. When the lower flow during 1937–38 is considered, however, the conclusion is that the bacterial pollution has actually decreased. Coliform organisms were materially lower in 1937–38 than in 1927–28 but the peak of pollution still remained just below New Brunswick.

Bacteriological data for winter and summer conditions are presented in tabular form. Both total and coliform organisms were lower during the summer months than during the winter period in 1937–38 which is the reverse of the 1927–28 data. Reduction in total and coliform organisms per cubic centimeter below Sayreville (Station 9, subject to tide) is considered to be due to increased dilution rather than to the salt content of the water. (Average chloride at this station, 1937–38, 4,817 p.p.m.; 1927–28, 2,300 p.p.m.)

In discussing the results the author states that comparison of data from the two surveys indicates that bacterial or sewage pollution has decreased throughout the main river, but that the chemical condition of the river is poorer especially above Bound Brook and below Somerville. The B.O.D. has increased and the oxygen saturation decreased. The poorer chemical condition is attributed to the greater quantities of more concentrated industrial wastes now entering the stream. The appearance of the river insofar as suspended solids and color are concerned is also adversely affected by the industrial wastes. These industrial wastes also seriously affect the self purification power of the stream as evidenced by lower nitrification in the presence of more ammonia in 1937–38.

The domestic sewage pollution load in the Raritan is rapidly decreasing due to increased treatment but the decreased load is not reflected by better stream conditions due to the inhibiting effect of the industrial wastes on self purification.

As far as the use of the river water is concerned the reduction of sewage pollution to be expected by increased treatment facilities appears to offset to some measure the increased intensity of industrial pollution. The author considers that continued industrial pollution will prevent the complete use of the water for industry, recreation and municipal water supplies although the natural unpolluted waters of the Raritan are highly satisfactory for such purposes.

All sewage treatment plants built in the basin, large or small, are modern. A brief summary of the processes and units used in the treatment plants is given in tabular form. The author states that the general trend in present day sewage treatment is best illustrated by the fact that of the 13 new plants constructed, eight are equipped for chemical treatment. Some will be operated with chemicals throughout the year and others will treat the sewage with chemicals during the summer season only (May–October).

On the basis of operation of two of the larger plants the degree of removal of sludge forming substances and B.O.D. is estimated. The Perth Amboy and New Brunswick plants both include screening, flocculation, chemical coagulation, settling, digestion, sludge dewatering, and chlorination and together treat a flow of 10 m.g.d. Over a six months operating period solids removal averaged 55 to 84 per cent depending on whether or not chemicals were used. The B.O.D. reduction was 34 to 63 per cent on the same basis. It is believed that, in general, the purification accomplished in the smaller plants will not be materially higher although some plants may produce effluents having 10 to 15 per cent less impurities with lower B.O.D. values. Based on known plant performance it is estimated that with all plants operating 125 tons of wet sludge daily will

be removed. In terms of oxygen the purification is equivalent to 8,750 pounds per day or to the addition of 90 to 120 m.g.d. of clean water.

Certain plants are required to chlorinate their effluents during the summer season (May–October) others during the entire year. This treatment is said to kill 99.9 per cent or more of the bacteria remaining in the effluent.

Despite the decrease in bacterial pollution in the river the numbers of coliform organisms are still large at several points where the river may be used for swimming. It is believed that this will be corrected when all plants are in proper operation.

In conclusion the author states that due to increased sewage treatment the river should rapidly improve so far as domestic sewage is concerned but that until pollution from industrial sources is alleviated chemical pollution will continue without the general improvement of the river expected from the investment in sewage treatment plants in the various communities.

PAUL D. HANEY

THE SYSTEM OF ACTIVATED SLUDGE–OXYGENATED WATER. PART IV. CONTROLLED ADSORPTION

BY DENIS DICKINSON

Jour. Soc. Chem. Ind. Trans., **59**, 78–80 (1940)

The author's thesis is that adsorption by activated sludge is controlled by the enzymes. The term "sorptive stage" is preferred to "clarification stage" because the former is taken to correspond to the period required for complete mixing and the highest purification rate while the latter term is of indefinite duration.

The reduction of methylene green by activated sludge in the presence of oxygen is represented as follows:

$X_r + d_o \rightleftarrows X_o + dr$ where X represents the enzyme and d the dyestuff, o and r the oxidized and reduced forms of these substances. The reduction time of methylene green by activated sludge was decreased as the temperature was raised from 13 to 24° C. At 43° C. the reduction was instantaneous but at temperatures higher than this the dye was not reduced. The reduced dye is retained on the sludge floc. The adsorption of the dye decreases as the temperature increases while the reduction increases with the temperature. No base exchange took place when a sludge treated with a solution of neutral red was mixed with a solution of methylene green.

The author concludes that adsorption is dependent upon biological process and precedes reduction. The floc is viewed as consisting of an inorganic nucleus surrounded by a layer of enzymatically active material.

The mechanism of the purification by activated sludge is represented by the following type—X representing an enzyme and S, a suitable substrate—

$$\begin{array}{ccc} \dfrac{X_0}{X_r} & \xrightarrow{\text{Adsorption}} & S_r\dfrac{X_0}{X_r+S_r} \\ \text{Re-}\uparrow\text{activation} & & \text{Bio-}\downarrow\text{oxidation} \\ \dfrac{X_0-8X_0}{X_r+8X_r} & \xleftarrow[\text{of } S_0]{\text{Desorption}} & \dfrac{X_0-8X_0+S_0}{X_r+8X_r} \end{array}$$

When activated sludge is aerated with sugar peptone and ammonium chloride the methylene green reduction time decreases up to 30 minutes of aeration of the mixture and thereafter it increases indicating an immediate adsorption followed almost immediately by biological action. It is possible that the nature, quantity, rate and order of the substances adsorbed are determined by the enzymes present. This would explain the differences in the behavior of different sludges towards the same sewage.

H. HEUKELEKIAN

STUDIES ON THE MECHANISM OF ACTIVATED SLUDGE PROCESS IN SEWAGE PURIFICATION

By Saburo Shibata

J. Soc. Chem. Ind., Japan Suppl. Bind., **42**, 257–264B, No. 8 (1939)

A mixture of activated sludge and sewage was aerated under laboratory conditions for a period of 189 hours. The optimum time of aeration was 4 hours. With increasing aeration time beyond this period the pH value decreased, the turbidity of the liquor increased, the volume of sludge settled decreased and the dissolved oxygen reached a saturation value of 96.3 per cent in comparison with tap water. Garbage liquor containing a somewhat higher amount of suspended solids than sewage, required 6 hours for optimum aeration when mixed with activated sludge. It is claimed that the additional time required to purify the garbage liquor was not due to the higher oxygen demand of garbage, but to the time required to beat the garbage particles to colloidal state. Garbage liquor behaved in a similar way to sewage with prolonged aeration. Garbage liquor aerated without activated sludge for a period of 160 hours did not show a decrease in pH value due to the absence of nitrification.

Reactivation of a sludge disintegrated by aeration for prolonged periods (189 hours) was attempted by dosing the sludge with sewage twice daily one with an aeration period of 4 hours and the other with an aeration period of 18 hours. The aeration periods were followed by settling and discarding of the supernatant liquor. The sludge recovered under these conditions and gave a maximum turbidity removal after 6 dosings. The pH value of the original sludge recovered more readily with but one dosing. Reactivation of a sludge disintegrated by prolonged aeration with the addition of garbage liquor was not as effective as with sewage. It was concluded that sewage rich in colloidal particles and half decomposed organic substances was most suitable for rapid reactivation of disintegrated activated sludge flocs.

It is claimed that an activated sludge mixture (1000 p.p.m. suspended solids) utilized during the first three hour period of aeration 60 mgm. of oxygen per liter per minute. During the next fifty hour period oxygen utilization rate was 40 mgm. per liter per minute. (*Abstractor's note:* These values are much higher than those reported by other investigators and are to be attributed to the method of determination which is based on difference in the oxygen content of ingoing and outgoing air.) By contrast the amount of CO_2 evolved therefore was low. From the discrepancy between the high amount of oxygen utilized and CO_2 produced the author came to the conclusion that the organisms take up CO_2 as their nourishment.

The decrease in pH value with prolonged aeration period is attributed to the increase in dissolved CO_2 and production of nitrates from ammonia.

The total nitrogen in the mixture of activated sludge and sewage increased from an initial value of 60 p.p.m. to 112 p.p.m. after 264 hours aeration. The author claims to have proven nitrogen fixation on the basis of these results. In fact the amount of nitrates formed during such a period of aeration is claimed to be higher than the original total nitrogen in the mixture.

H. Heukelekian

BIOLOGICAL DECOMPOSITION OF PHENOL BY MEANS OF ACTIVATED SLUDGE WITH REFERENCE TO THE METHOD OF BREAKDOWN OF ITS COMPOSITION

By Akano Rokuro and Cho Jinnosuke

Mitt. Mediz. Akad. Kioto, **27**, 389–402, 1 (1939)

In an effort to determine the mechanism of decomposition of phenol by activated sludge and to demonstrate whether certain intermediate products were formed during the

decomposition, gas exchange (oxygen absorption and carbon dioxide production) and spectographic studies were made during 24 hours aeration with activated sludge. Although most of the phenol added (50 p.p.m.) had disappeared, only a part of the expected values of oxygen consumption and CO_2 production were obtained assuming a complete decomposition of the phenol added. About one-half of the phenol was not completely decomposed on the basis of oxygen consumption and CO_2 production values and yet phenol as such could not be demonstrated by the diazo reaction. After 48 hours aeration 93 per cent of the theoretical oxygen consumption and CO_2 production values were obtained. Search for intermediate products such as muconic acid, acetone substances, benzoic acid, resorcin, pyro-catechol, hydroquinone, alcohols and aldehydes gave negative results. Spectographic analyses showed a quantitative decrease of the phenol but not a qualitative change. It was concluded that phenol is not converted to any other aromatic combination during biological oxidation by activated sludge but that it decomposes directly into carbon dioxide and water by means of the breaking up of the ring.

H. HEUKELEKIAN

BUFFER VALUES OF SEWAGE DURING PURIFICATION

By ROBERT S. INGOLS AND H. HEUKELEKIAN

Ind. and Eng. Chem., 32, 401 (March, 1940)

A systematic study of buffer value of sewage during purification indicates that compounds of the ammonium carbonate type were responsible for most of the buffer action. Fatty acids, phosphates, amino acids, uric acid, humic acid, peptones and peptides account for the remaining buffer action.

Sewage subjected to aeration, without addition of sludge, showed only a gradual change in buffer value. During the first few hours there was a slight upward trend due to expulsion of carbon dioxide. No change was noted during the next two days. From the sixth to the eighth day oxidation of organic matter resulted in a reduction of the acid buffer material. At the end of twelve days, simultaneously with complete nitrification of ammonia, most of the buffer value was expended.

Aeration of sewage-sludge mixtures showed a rapid reduction of the buffer value. The rate of reduction increased as the sludge concentration was increased. Dilution of sewage in which the sludge concentration was kept constant also tended to increase the rate of reduction of buffer value. These changes were brought about by the following processes acting simultaneously; (*a*) loss of free CO_2, (*b*) oxidation of organic matter, (*c*) oxidation of ammonia to nitrates, (*d*) the production of more CO_2 as the ammonia disappears.

Under plant conditions the marked changes noted in the laboratory experiments were not reproduced. This discrepancy is explained by the fact that there was serious short circuiting through the tanks at the plant at which the experiment was conducted.

The same tendency toward reduction of buffer value was noted in trickling filter plants.

E. HURWITZ

RESPIRATORY QUOTIENT OF ACTIVATED SLUDGE AND OF ACTIVATED SLUDGE—SEWAGE MIXTURES

By C. M. SAWYER AND M. STARR NICHOLS

Ind. and Eng. Chem., 31, 1042 (Aug., 1939)

The possibility of using carbon dioxide production as a measure of sewage oxidation and the need for data concerning the mechanism of activated sludge-sewage oxidation led to studies which attempted to correlate the actual usage of oxygen with carbon dioxide

produced during oxidation of sewage in aerated sewage-activated sludge mixtures. The results are reported as the "respiratory quotient," R.Q., which is defined as the volume of CO_2 produced divided by the oxygen used.

The instrument used for these studies, the "Oxy-Utilometer" (Oum.) is described in detail. Activated sludge-sewage mixtures are aerated in a closed system. Carbon dioxide produced during oxidation is absorbed in alkali and measured by titration. The oxygen used is measured by displacement of water from a burette and is replenished as used from an oxygen balloon.

Sludges from different sources show marked differences in respiratory quotient, R.Q. The R.Q. is also influenced by sludge concentration but the effect is slight and does not compare in magnitude with the effect shown by different sludges.

Temperature variations from 10–25° C. had no effect on the R.Q. values.

Oxidation of sewage with different sludges gave R.Q. values of 0.79 and 0.89. Keeping the sludge constant and varying the source of sewage gave R.Q. values of 0.78 and 0.64.

Addition of glucose increases the R.Q. value over the control. Peptone, urea, ammonium chloride cause a decrease in R.Q. value.

Storage of activated sludge from 0–9 hours did not effect the R.Q. However the utilization of oxygen and the production of CO_2 is materially increased. Age of sewage in a sewage-sludge mixture did not effect the R.Q. appreciably.

Little change in R.Q. is caused by time on sludge-sewage mixtures. The R.Q. determined at the end of three and five hours was 0.82 and 0.80, respectively.

Since the R.Q. for different sludges and sewage-activated sludge mixtures vary so widely, it is doubtful if carbon dioxide measurements can be used as a means for determination of oxidation rates. However it is thought further study may result in showing relationships between R.Q. and such sludge characteristics as activity, biological composition, ash content, bulking and dewatering.

E. Hurwitz

FERRIC OXIDE HYDROSOLS AS COAGULANTS IN WASTE TREATMENT

A. L. Elder and S. W. Stahl

Ind. and Eng. Chem., **31**, 925 (July, 1939)

Studies of the efficiency of ferric oxide hydrosols on coagulation of sewage and industrial wastes revealed that these hydrosols were less effective than ferric chloride or ferric sulfate. Dialyzed hydrosols were less effective than undialyzed hydrosols.

Tests were made using domestic sewage and milk waste. Removals of 5-day B.O.D. with varying amounts of coagulant are shown on graphs from which the table given below has been prepared:

Per Cent 5-day B.O.D. Removed

	Domestic Sewage					Milk Waste				
	Parts per Million Coagulant as Fe									
	2	4	6	8	10	10	20	30	40	60
$FeCl_3$	19	37	45	49	50	40	58	63	66	66
$Fe_2(SO_4)_3$	16	29	40	46	49	50	61	66	67	67
$Fe(OH)_3$ Sol.	19	35	42	45	46	24	51	59	62	64
$Fe(OH)_3$ Sol. dialyzed					38					34

The differences in efficiency are due to particle sizes before coagulation, since small particles expose greater sorptive surfaces, and to differences in the physical character of the floc formed.

Particle sizes increase in the order: ferric chloride, ferric oxide hydrosol, and ferric oxide hydrosol dialyzed. The floc formed by the hydrosols was dense and granular permitting only a minimum of sorbed matter to be enmeshed in the crystal lattice of the particle. On the other hand ferric chloride produced a gelatinous floc capable of adsorbing and carrying down a large amount of organic matter.

E. HURWITZ

REFERENCES TO SEWAGE LITERATURE

January–May, 1940

American City. Volume 55

January, 1940 (No. 1).

"Safe Operation of a Sewerage System," p. 11.

"The Control of Filter Flies," p. 11.

"Cheese-Whey Removal, Monroe, Wisconsin." Theodore Reed Kendall, pp. 49–51.

February, 1940 (No. 2).

"Sewers and Sewage Plants," p. 11.

"New Primary Sewage Plant at Ypsilanti, Michigan," pp. 47–49.

"Sewage Treatment Plant Built on Several Levels (Granite Falls, Minn.)," pp. 51–52.

March, 1940 (No. 3).

"Well-Landscaped Sewage Works Attracts Distant Visitors (Bloomington-Normal, Ill.)." J. L. Hasbrouck, pp. 37–38.

"Malvern, Arkansas, Builds New Sewage Works." D. Y. McDowell, pp. 46–47.

April, 1940 (No. 4).

"City Sewage and Trade Wastes Treated Separately (Circleville, Ohio)." Ervin F. Leist, pp. 64–66.

"Close Control of Operation of Small Sewage Plant (Sheboygan Falls, Wis.)." Edmund Malinowski, pp. 77–79.

May, 1940 (No. 5).

"New Sewage Treatment Plant for Mason, Michigan." W. F. Shephard, pp. 46–48.

"Sewage Treatment Plant Handles Steel-Mill Wastes." R. F. Snyder, pp. 60–62.

Engineering News-Record. Volume 124

January 4, 1940 (No. 1).

"Sewage Treatment Coupled with Irrigation." F. M. Veatch, pp. 48–50.

"Bentonite Stops Sewer Leakage." Emerson C. Hallock, p. 63.

February 15, 1940 (No. 7).

"Sanitary Engineering." Edw. J. Cleary, pp. 226–228.

February 29, 1940 (No. 9).

"Los Angeles Plans to Spend $32,000,000 for Handling Sewage," pp. 315–316.

March 14, 1940 (No. 11).

"Pointers on Sewage Disposal Service." Peter A. Smith, pp. 389–391.

"Cost Data on Clay Sewers." Morgan W. Hayes and I. W. Mendelsohn, pp. 391–392.

"Sludge Filtration and Incineration," pp. 393–396.

"Sewer Maintenance Hints," pp. 396–397.

"Notes on Sewage Disposal." Willem Rudolfs, p. 398.

May 9, 1940 (No. 19).

"Notes on Sewage Disposal." Willem Rudolfs, p. 668.

May 23, 1940 (No. 21).

"Building a Big Sewer in Bad Ground." William B. Fowler, pp. 720–723.

"Diagnosis for a Sick River." Edward J. Cleary, pp. 716–719.

Municipal Sanitation. Volume 11

January, 1940.

"Settling and Filtration at Denver Works." F. M. Veatch, pp. 8–10.

"Sewerage for 18,000 Soldiers." H. E. Moses, pp. 11–13.

February, 1940.

"Developments in Sewage and Waste Treatment During 1939." Willem Rudolfs, pp. 57–63.

"Pollution Control—Where Does it Stand?" Abel Wolman, pp. 64–66.
"National Census of Sewage Treatment Projects," pp. 72–81.
"Sewering a Town on the Sound." Clinton L. Bogert, pp. 82–84.
"Modern Sewerage Works for Muncie (Ind.)." A. A. Burger, pp. 85–87.
"When City is Liable for Injury to W. P. A. Workman." Leo T. Parker, pp. 88–90.

March, 1940.

"Activated Carbon Aids Sludge Drying." Gordon J. Wiest, pp. 140–142.
"Activated Sludge Plant Corrects Pollution Litigation." E. Sherman Chase, pp. 143–146.
"New Law on Liability for Municipal Nuisance." Leo T. Parker, pp. 157–159.

April, 1940.

"Sludge Incineration at Columbus," pp. 185–186.
"Solving Design Problems. I. Settling Tanks." Rolf Eliassen, pp. 187–188.
"Three Steps to a Modern Plant." Nicholas Miljevic and Newell L. Nussbaumer, pp. 189–192.
"A City's Liability for Injury to Public." Leo T. Parker, pp. 197–198.

May, 1940.

"Landscape Treatment at Sewage Works." Charles B. Tilton, pp. 228–231.
"Glen Cove Modernizes Its Treatment Plant." Nathan N. Wolpert, pp. 232–233.
"Solving Design Problems. II. Digestion Tanks." Rolf Eliassen, pp. 234–239.
"Protecting Goldfish Ponds from Cannery Wastes." John B. Funk, pp. 245–246.
"Time Limit for Filing Pollution Suits." Leo T. Parker, pp. 247–249.

Public Works. Volume 71

January, 1940 (No. 1).

"Multiple Digestion of Sludge at Grand Forks, N. D." K. W. Riley, pp. 12–14.
"Disposal of Garbage with Sewage." K. C. Lauster, pp. 25–26.
"Use of Sewage Effluent in Irrigation," pp. 32–35.

February, 1940 (No. 2).

"Trickling Filters—Their Design, Construction and Operation. I." Editorial Staff, pp. 26–37.

March, 1940 (No. 3).

"Trickling Filter Design, Construction, and Operation. II." Editorial Staff, pp. 23–29.

April, 1940 (No. 4).

"Design Notes for Camp, Residential, Hotel and Other Small Sewage Treatment Works," pp. 60–61.
"Bio-Filters, Aero-Filters and Other High Capacity Filters. III." Editorial Staff, pp. 62–74.

May, 1940 (No. 5).

"Attractive Sewage Treatment Plant Located at Edge of Village (Excelsior, Minn.)." E. E. Bardwell, pp. 16–18.
"Trickling Filter Equipment and Operation. IV." Editorial Staff, pp. 28–33.

Water Works and Sewerage. Volume 87

January, 1940.

"Sewage Analyses." Richard Pomeroy, pp. 33–37.
"A Sewage Screenings Problem." Orie G. Hendryx and Kingsley Carrington, p. 40.

February, 1940.

"The Disposal of Sewage and Industrial Wastes Developments and Trends in 1939." F. W. Mohlman, pp. 47–58.
"Equipping the Sewage Plant Laboratory." Norman C. Wittwer, pp. 70–75.

March, 1940.

"The Growing Importance of Industrial Waste Disposal." F. W. Mohlman, pp. 93–101.

"'Package Delivery' Waste Treatment Plants." E. B. Mallory, pp. 102–106.
"The New Treatment Plant of Hibbing." Charles Foster, pp. 115–119.
"Complete Sewage Disposal for a Small Community." Morrell Vrooman, Jr., pp. 130–133.

April, 1940.

"Grit Removal from Sewage." W. A. Kivell and N. B. Lund, pp. 176–185.
"Grit Chambers." M. B. Tark and J. J. Gilbert, pp. 186–189.
"Grit—Its Collection and Washing." R. D. Nichols, pp. 190–193.
1940 Reference and Data Section, pp. 1–207.

May, 1940.

"The Construction of Sewage Treatment Works." Abel Wolman, pp. 201–204.
"Some Considerations to the Question of Sludge Density." Gordon J. Wiest, pp. 216–217.
"Packinghouse Waste Treatment." L. R. Howson, pp. 217–222.

CONVENTION NEWS

Release by Anthony Anable, Attendance and Publicity Chairman

PLANS FOR THE FIRST ANNUAL CONVENTION OF THE SEWAGE WORKS FEDERATION IN CHICAGO

The First Annual Convention of the Federation of Sewage Works Associations, to be held at the Sherman Hotel, Chicago, October 3rd to 5th inclusive, has been in the planning stage for some time, following the receipt of an invitation from the Central States Sewage Works Association to hold this meeting in Chicago, in conjunction with its own annual meeting. Questionnaires sent out some time ago, to the officers of the 22 American and Canadian local associations, revealed an overwhelming sentiment—82.6 per cent of the votes—for an annual meeting in 1940, and a large preference—59 per cent of the votes—for a convention city in the middle west.

Tentative plans for the Chicago meeting call for the usual sessions for the presentation of technical papers, an extensive manufacturers' exhibit of materials, supplies and equipment, banquet and smoker and a trip to the Southwest Treatment Plant of the Chicago Sanitary District. Operators' breakfasts and ladies' entertainment are also planned. The Sherman Hotel, convention headquarters, is making special rates for members. The largest sewage works convention in history is confidently expected, with an estimated attendance of at least 600.

The General Convention Committee is headed by G. J. Schroepfer, Chief Engineer of the Minnesota-St. Paul Sanitary District, and is composed of Morris Cohn, Schenectady; F. W. Gilcreas, Albany; F. W. Mohlman, Chicago; W. J. Orchard, Newark, and B. A. Poole, Indianapolis. Mr. Poole is the President of the Central States Sewage Works Association.

Forty-seven other men, actively engaged in the sanitary engineering field, have been appointed to working committees. The names of these working committees and their Chairmen follow:

Local Arrangements	F. W. Mohlman, Chicago
Finance	W. J. Orchard, Newark
Program	C. K. Calvert, Indianapolis
Attendance and Publicity	Anthony Anable, New York
Manufacturers and Exhibit	C. T. Birkeness, Chicago
Entertainment	H. E. Schlenz, Chicago
Hotel and Registration	E. Hurwitz, Chicago
Transportation and Inspection Trips	L. M. Johnson, Chicago
Ladies Entertainment	Mrs. Paul Hansen, Chicago

STRONG NATIONAL SEWAGE WORKS FEDERATION MAY RESULT FROM FIRST ANNUAL CONVENTION IN CHICAGO NEXT OCTOBER

A revitalized and materially strengthened Federation of Sewage Works Associations will probably be launched in Chicago next Fall, if affirmative action is taken as expected on plans now being formulated by the Federation's Committee for Expansion and Reorganization, headed by Charles A. Emerson of New York, and composed of 19 other members of the local sewage works associations. The meeting at which this most important matter will be opened up for discussion and action is the FIRST ANNUAL CONVENTION OF THE FEDERATION OF SEWAGE WORKS ASSOCIATIONS, to be held at the Sherman Hotel, Chicago, October 3rd, 4th and 5th, in conjunction with the Annual Meeting of the Central States Sewage Works Association. The total membership of the 25 local associa-

tions affiliated with the Federation is 2,750, and an attendance of 600—an all time high—is expected at this convention.

No final action can be taken on the proposals of the Committee for Expansion and Reorganization, prior to the meeting in Chicago. However, members of the local associations, who no doubt have heard many conflicting rumors regarding the reorganization plan, may be interested to learn at this time, the aims of the movement and precisely how it is proposed to realize these aims in practice.

First and foremost, it is the basic aim of the movement now afoot, to strengthen—not to change—the set-up of the Federation, in order to improve the professional position of all workers in the broad field of sewage treatment, particularly sewage plant operators. These public servants need and deserve a strong national voice. They need a strong, central co-ordinating group. They need, the Reorganization Committee believes, the necessary training and education to secure continual advancement on a merit basis, together with civil service or some other guaranty of tenure of office.

A strong, national Federation is proposed by the Committee, as the best possible means for improving the professional, economic and social status of the individual members of the local associations. Furthermore, such a strong national Federation is expected to take a leading and active part in advancing, on a national scale, the best tenets of modern sanitary engineering practice, for the ultimate benefit of the people as a whole.

In its new and revitalized form, it is proposed to make no change whatsoever in the basic Federation set-up as it has existed for the past 12 years. It is to continue, as before, as a Federation not of individual members, but of local affiliated associations. There is definitely to be no interference from headquarters, direct or indirect, with the activities of the local, member associations which are to retain, just as they always have, complete freedom of action with respect to local affairs.

How then, one may ask, are these aims to be realized. First, it is planned to establish a strong, central executive office with a full time Executive Secretary and stenographer, to take over all routine business; to procure advertising for the Journal; to maintain closer contact with the member associations and thus to put the business end of the Federation on a par with that of other national, professional associations.

Committee work will be greatly broadened in scope and strengthened, particularly with respect to the establishment of uniform standards of procedure in plant design, plant operation and equipment. Committee work will be amply financed by the appropriation of special funds for this purpose.

It is proposed that the scope of the SEWAGE WORKS JOURNAL be extended, by changing this most valuable publication from a bi-monthly to a monthly basis. An annual Federation convention is proposed, to be held alternately in different cities throughout the country, with extensive provision for exhibits of manufacturers and supplies. In addition, means may be provided for similar exhibitions at the meeting of the local associations.

Funds to finance the expanded work of the Federation are to be provided by increasing the dues for full members to $3.50 per year, and for operator members to $2.50 per year. New forms of membership are also being considered, such as honorary, corporate, associate and sustaining.

The president and vice president of the Federation are to be selected from the entire membership of the local Associations, not solely as at present, from the members of the Federation's Board of Directors. Only one director is to represent each member association, tenure of office is limited to three years, and no officer or director may succeed himself.

So much then, for the fundamentals of the plan prepared by Mr. Charles A. Emerson and his Committee on Expansion and the Reorganization, all of which will be dealt with at Chicago, next Fall. A word or two seem in order on exactly what the plan does *not* propose to do, to allay rumors which have gained a fair degree of credence in certain parts of the country, and led to a good deal of confusion.

The reorganization plan definitely does not envisage any combination whatsoever with any other technical association, such as the American Water Works Association, the American Public Health Association, or the American Public Works Association. The sponsors of the plan have not entered into any agreement with any group of manufacturers for financing the work of the revitalized Federation. It should be mentioned, how-

ever, that a plan is being considered to form a manufacturers' group, to be affiliated with the Federation, to take charge of that phase of the Federation's work in which the manufacturers and suppliers are primarily interested—namely, exhibits of equipment and materials at the national and local conventions.

Release by William J. Orchard, Chairman of the Special Committee of the Water and Sewage Works Manufacturers' Association, by order of the Board of Governors

WATER WORKS MANUFACTURERS' ASSOCIATION BECOMES WATER AND SEWAGE WORKS MANUFACTURERS' ASSOCIATION

At a meeting of the Executive Committee of the Water Works Manufacturers' Association, held on Friday, June 28, 1940, the new Constitution and By-Laws presented at the Annual Meeting of the Association in Kansas City in April, were adopted. This was the result of a mail ballot held at the direction of the Executive Committee. 111 of the 143 members of the Association cast ballots: 2 ballots were indefinite, 9 voted "No" and 100 voted "Yes." The Executive Committee, therefore, declared the new Constitution and By-Laws in effect.

The Special Committee on Sewage Works Activities, composed of W. W. Brush, W. T. Chevalier, J. A. Kienle, D. F. O'Brien and Wm. J. Orchard, Chairman—that has been in operation since the fall of 1939, was continued and charged with the responsibility of taking the necessary steps to put the new Constitution and By-Laws in effective operation.

Under the new By-Laws the Executive Committee becomes the Board of Governors of the new Association.

Under the new set-up, there will be four classes of membership in the Association:

Class A members—those engaged in both water works and sewage works activities.
Class W members—those engaged in water works activities.
Class S members—those engaged in sewage works activities.
Class B members—a limited sectional membership.

There will be two Divisions of the Association: a Water Works Manufacturers' Division made up of Class A and Class W members, and a Sewage Works Manufacturers' Division made up of Class A and Class S members. In due course the members interested will elect a Water Works Executive Committee of 9 members and a Sewage Works Executive Committee of 9 members, who will be responsible to the Board of Governors for the activities of the two Divisions.

It is anticipated that the Special Committee will be prepared to present to the Board of Governors and to the members of the Association, the water works phases of the reorganization during the New England Water Works Convention to be held in New York City September 24–27 and that the Committee will be prepared to present and take the necessary steps in connection with the Sewage Works Division at the First Annual Convention of the Federation of Sewage Works Associations to be held in Chicago, October 3–4–5.

The steps taken by the Special Committee and by its Chairman, William J. Orchard, in connection with the forthcoming Sewage Convention in Chicago were unanimously approved by the Board of Governors and the Committee was instructed to continue to use its best efforts in making the Chicago Convention outstanding in every respect.

The Committee was also instructed to proceed immediately to open the membership of the Association to manufacturers of materials, supplies and equipment used in connection with sewerage and sewage disposal.

Note by Editor: At a meeting of the Executive Committee for the Chicago Convention on July 18th, it was agreed that manufacturers not members of the Water and Sewage Works Manufacturers' Association may exhibit at this Convention, if their representatives pay the registration fees ($7) required of commercial representatives (as compared with $3 for non-commercial registrants).

Announcement

Program and final details of meeting will be announced in our September issue.

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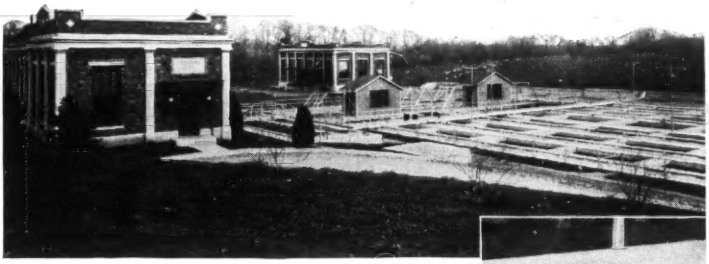

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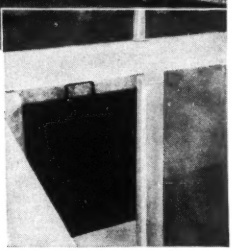

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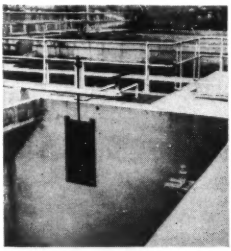

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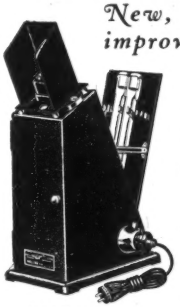

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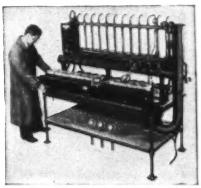

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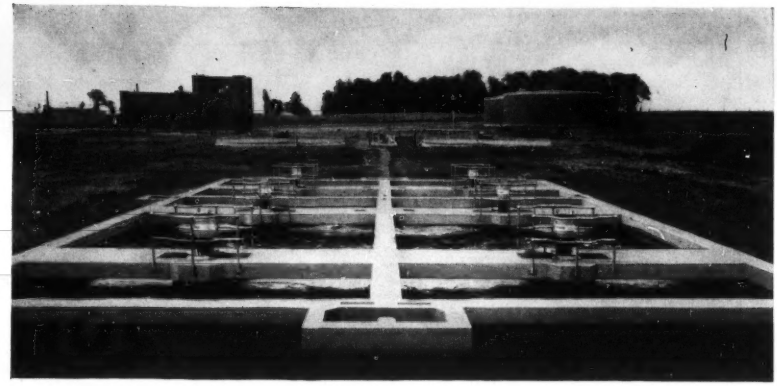

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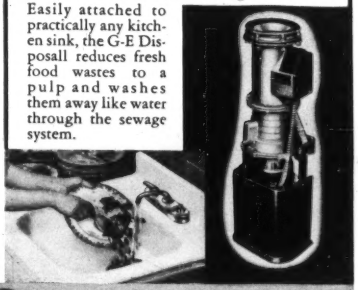

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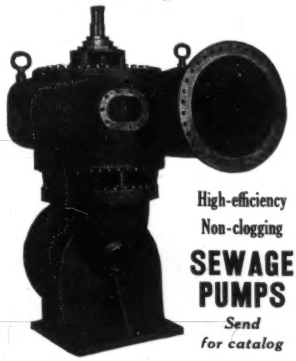

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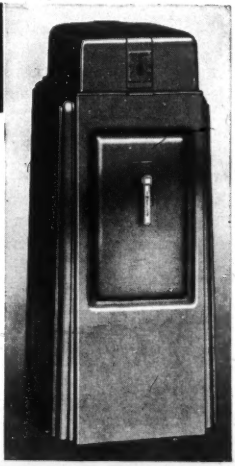

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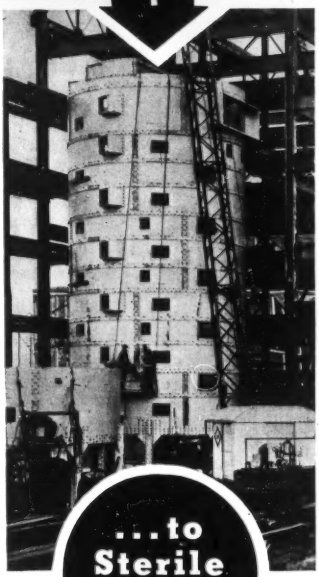

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INDEX TO ADVERTISERS

	Page
Albright & Friel, Inc.	22
Aluminum Co. of America	5
Alvord, Burdick & Howson	22
American Brass Company, The	17
American Journal of Public Health	21
American Well Works	23
Black & Veatch	22
Buck, Seifert & Jost	22
Campbell, Davis & Bankson	22
Carborundum Company	25
Cast Iron Pipe Research Assn.	14
Chain Belt Company	4
Chapman Valve Mfg. Co.	6 and 7
Chicago Pump Company	18
De Laval Steam Turbine Co.	20
Dorr Company, Inc., The	2
S. R. Dresser Mfg. Co.	13
Eimer & Amend	20
Filtration Equipment Corp.	3
Foxboro Company	10
Gascoigne, George B., & Associates	22
General Chemical Co.	9
General Electric Co.	24
Greeley and Hansen	22
Hellige, Inc.	20
International Filter Co.	26
Johns Manville Corp.	11
Knowles, Inc., Morris	22
Link-Belt Company	8
Metcalf & Eddy	22
Morris Machine Works	26
Nichols Eng. & Research	27
Norton Company	12
Pacific Flush-Tank Company	15
Pennsylvania Salt Mfg. Co.	16
Precision Scientific Co.	20
Tennessee Co.	24
Wallace & Tiernan Company, Inc.	Back Cover
Whitman, Requardt & Smith	22
Worthington Pump & Machinery Corp.	19

When writing these, please mention the

SEWAGE WORKS JOURNAL

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EQUIPMENT BY W&T

"Odor control is further augmented with two W&T Master Feed Solution Type Chlorinators of 2000 lbs. capacity per day and one W&T Dry Feed Type Chlorinator having a capacity of 1000 lbs. per day. The Solution Feed machines will be used for producing chloride of iron or chlorinated copperas or for feeding chlorine to the grit channels. The Dry Feed Chlorinator is used in 'aero-chlorination' for grease removal, dry chlorine being fed into the lines leading to the second pass of this odor control unit . . . When and if chemical precipitation is needed for reducing the load going to the filters, the air supply can be adjusted to provide for chemical mixing in this structure. Two W&T Dry Feed machines with capacities from 50 to 750 lbs. of iron sulphate per hour will be used for feeding dry chemicals to a chemical mixing box."

(From "The New Sewage Treatment Plant of Dallas" by R. M. Dixon, Sr. Engr., D.P.W. Water Works & Sewerage, Vol. 87, No. 6)

Selection of W&T equipment for this Dallas multi-purpose installation was made, as are most chlorinator installations, on the basis of performance by the thousands of W&T chlorinators now in service throughout the world.

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